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PROCEEDINGS
of
The Institute of Radio Engineers

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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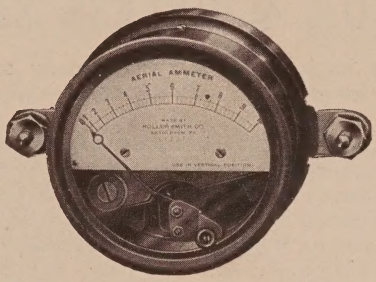

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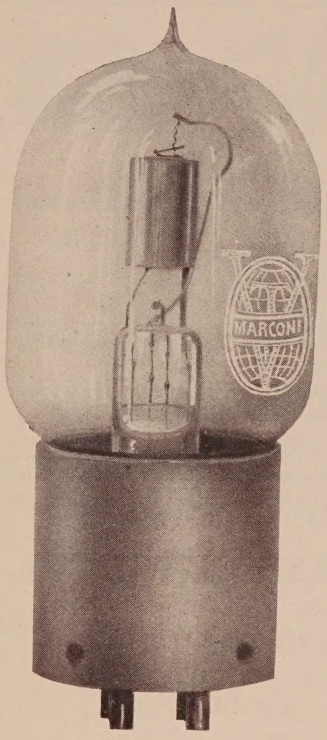

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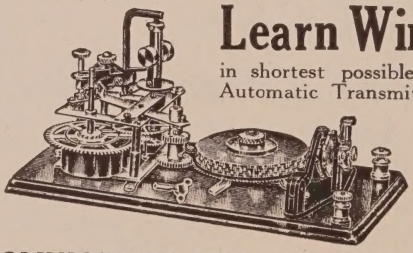

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of

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EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED EVERY TWO MONTHS BY
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THE INSTITUTE OF RADIO ENGINEERS

announces with regret the death of

Harold C. Schreiner

Mr. Schreiner was born February 9, 1895, in Chicago, Illinois. In June, 1917, he left the college which he was then attending in order to join the Signal Corps. At that time, he had completed three years' work of the course in electrical engineering. He had previously enlisted in the Signal Corps three days before the declaration of war by the United States.

In October, 1917, he was sent to Camp Custer, Battle Creek, Michigan. A month later, he was transferred to the Radio School at College Park, Maryland. His high grade in his work there led to his being commissioned as an officer. He was assigned to the 8th Signal Battalion, 4th Division, which was then stationed at Camp Green, Charlotte, North Carolina.

The battalion to which he was attached was ordered to France in May, 1918. He fought at Chateau Thierry, and later in the Argonne Sector. On September 26th, Lieutenant Schreiner was wounded. Within three weeks of this time, he succumbed to the effects of this injury. He was known among his associates and men as an officer of efficient and manly character.

Medal of Honor

OF THE BOARD OF DIRECTION

Attention is called to an alteration in the terms of award of the Medal of Honor of the Board of Direction of The Institute of Radio Engineers.

At its meeting on May 16, 1919, the Board of Direction decided that, in order to broaden the scope of this award and to enable suitable recognition of eminent service in the radio art, regardless of the time of performance of such service:

The award in question may be made regardless of the time of performance or publication of the work on which the award is based.

The other conditions of the award, as set forth in the April, 1919, issue of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, on pages 95 and 96, will remain unchanged.

SHORT WAVE RECEPTION AND TRANSMISSION ON GROUND WIRES (SUBTERRANEAN AND SUBMARINE)*

By

Lieutenant-Commander A. Hoyt Taylor

(United States Naval Reserve Force)

The purpose of this article is to report briefly some of the work done by the writer for the Navy Department along the lines indicated by the above title. No attempt will be made to give a complete history of all work which has been done on ground wire systems, as this would exceed the scope of this report. This paper will deal mainly with the behavior of short waves on underground and underwater systems, but in order to get a logical story of this work, it will be necessary to include frequent references to long wave work.

1. Clark's Experiments

During the month of April, 1909, Mr. George H. Clark, then Radio Sub-Inspector, United States Navy, conducted underwater experiments at the Navy Yard, Washington and at the Navy Yard, Norfolk, Virginia, using two 30-foot (9.2 m.) launches equipped with two insulated wires 17 feet (5.2 m.) long, submerged 4 feet (1.2 m.) below the surface, being connected to the transmitting and receiving apparatus thru a fixed condenser of capacity 0.003 microfarad. These wires were placed at an angle of 180° from each other below the surface, and extended out from the center of the launch. It was possible to receive signals from the Navy Yard Station, Washington, at 12 miles (19 km.) distance. Working with one-eighth kilowatt at 425 meters, between the launches, it was possible to communicate a distance of 75 yards (69 m.). Further experiments were conducted on board a tug boat off Norfolk. Copper plates were attached to insulated wires and one plate suspended over the bow into the water and the other plate suspended over the stern into the water. The wires leading up from the water to the receiving apparatus

* Received by the Editor, January 20, 1919.

were screened by the use of brass pipe and copper mesh. A fixed condenser of the same capacity as the one used at Washington was used in these experiments. Signals from the Navy Yard, Norfolk, were received at a distance of 15 miles (24 km.). All experiments showed a marked directive effect, received signals showing a great decrease in strength when tug boat and launches were lined up within 60° to 90° of the direction of the sending station. It is apparent that these early tests by Mr. Clark, done with crystal detectors, had to be carried out in such close proximity of the sender, that the results were partly due to real wave action and partly due to conduction currents from the sender. Owing to phase differences, these effects conspire in some directions and not in others, thus giving peculiar and abnormal directive effects. Mr. Clark evidently did not use long enough receiving wires for the best results. As the result of his experiments, the Bureau of Steam Engineering concluded that altho underwater work was possible for short distances, it was not promising for long distance work. It was also believed at that time that underwater communication would only be possible in fresh water. The experiments were, therefore, abandoned. The use of submarine sending and receiving wires in the form of a loop will not be discussed in this report, as that should properly be made the subject of a separate report.

2. New Orleans Experiments

On December 1, 1916, Admiral W. S. Smith and Commander S. C. Hooper inspected the system of underground radio reception which had been brought to the attention of the Navy Department by Mr. J. H. Rogers at Hyattsville, Maryland. Mr. Rogers demonstrated that trans-oceanic signals were easily readable on underground wires. At the same time he went out in a small boat on a lake near Hyattsville and transmitted from the boat with underwater wires to a station at his home about two miles (3.2 km.) away. On March 6th, 1917, the Bureau arranged to have Mr. H. H. Lyon, who had been associated with Mr. Rogers, proceed to New Orleans, Louisiana, with the idea of developing this system for Naval use, bearing especially in mind its possible value at distant control stations and for use between submerged submarines and other ships. Mr. Lyon reported to the Commandant of the Naval Station, New Orleans, and started work under Lieutenant-Commander E. H. Loftin, who was then

District Communication Superintendent for the 8th Naval District. The following is a copy of a report made by Lieutenant-Commander Loftin under date of April 14, 1917, to the Bureau of Steam Engineering, on underground radio experiments.

"Experiments have been in progress during the past three or four weeks at this Station to ascertain the adaptability of underground wires for receiving radio signals. These experiments have been conducted by Mr. H. H. Lyon, Radio Expert, assigned to this duty by the Bureau of Steam Engineering, and Chief Electrician C. W. Jordan, United States Navy, under the supervision of the District Communication Superintendent.

"A standard copper conductor of 23,000 circular mils (11.6 sq. mm.) (7 twisted strands) having rubber insulation of about 0.15 inches (0.38 cm.) thickness, has been used thruout. All wires are buried to a depth of about one foot (0.3 m.), the earth surrounding being practically saturated with water at all times.

"One conductor was laid in an approximate northeast and southwest direction, 1,400 feet (427 m.) extreme length, or 700 feet (213 m.) on each side of the receiver. This wire was cut into sections so that the total length, or several fractions of the total length, could be cut in. In addition to this long wire, two short ones, 300 feet (92 m.) over all, or 150 feet (46 m.) each side of the receiver, were laid parallel to and 10 feet (3.1 m.) from it, one on each side. A switch was arranged to connect either one or both of these wires to the receiver.

"For arc reception a 'BA' type receiver and an ultra-audion oscillating detector were used. Two pairs of telephones were connected in series, one pair being bridged with a type 'A' audibility meter. This was found advisable on account of disturbance of wing potential by the meter.

"The following results were obtained with arc signals:—

"(a) 1,400-foot (427 m.) antenna, grounded at the extreme ends to large plates buried in moist earth, 0.0025 microfarad variable condenser in series for tuning.

Date	Station	Wave Length	Signal Audibility	Static* Audibility	Static Audibility, Main Antenna
Mar. 30	Arlington	7,500	1,000	20	.....
Mar. 30	Tuckerton	.....	1,000	20	.....
Mar. 30	Darien	7,000	250	20	.....
Mar. 30	Pt. Loma	7,000	200	20	.....
Mar. 31	Arlington	7,500	1,000	50	10,000
Mar. 31	Tuckerton	.....	1,000	50	10,000
Mar. 31	Darien	7,000	1,000	50	10,000
Mar. 31	Pt. Loma	7,000	400	50	10,000

"(b) 1,400-foot (427 m.) antenna, ends not grounded by plates, 0.0025 microfarad variable condenser in series for tuning:

Date	Station	Wave Length	Signal Audibility	Static Audibility
April 2	Arlington	7,500	1,500	0
April 2	Tuckerton	.....	1,500	0
April 2	Darien	7,000	500	0
April 2	Pt. Loma	9,800	500	0

"NOTE—These arc stations could be read without interference from the Station 5 kw. spark set 300 feet (92 m.) away. Interference began when down to about 5,000 meters.

"(c) 300-foot (92 m.) antenna, ends not grounded, 0.0025 microfarad variable condenser in series for tuning:

Date	Station	Wave Length	Signal Audibility	Static Audibility
April 2	Arlington	7,500	300	0
April 2	Tuckerton	.....	300	0
April 2	Darien	7,000	100	0
April 2	Pt. Loma	9,800	100	0

* Static disturbances here referred to are identical with what are also termed "strays," that is, the sum total of all irregular disturbances of reception irrespective of their (natural) origin.—EDITOR.

"Up to 1,400 feet (427 m.) of wire, the strength of the signal seems to be about in direct proportion to the length of the wire. The directional effect appears to be pronounced. Darien, which is about 80° off the line of antenna, is weaker than Arlington. On the main antenna, Darien is received about 30 per cent. stronger than Arlington.

"The 'B A' receiver, with its static (capacitive) coupler, is not very satisfactory for this form of reception on account of its lack of selectivity and smooth variation of primary inductance.

"At 9:00 P. M., April 7th, it was possible to copy signals from Tuckerton with ease, while static on the main antenna made it impossible to read any arc signals.

"The following results were obtained with spark signals:

"(a) 300-foot (92 m.) wires in parallel, ten feet (3.1 m.) apart, a 0.002 microfarad condenser in series with the primary coil of a Telefunken receiver to obtain 600 meters.

Date	Station	Wave Length	Signal Audibility	Static Audibility	Signal Audibility, Main Antenna	Static Audibility, Main Antenna
April 2	Point Isabel	600	15	..	....	....
April 2	Tampa	600	200	0	....	3,000
April 2	Port Arthur	600	150	0	....	3,000
April 2	Pensacola	1,200	20	0	100	150
April 2	Ft. Sam Houston	....	150	..	....	....

"It was planned to take comparative signal strengths on main antenna and underground antenna during the weekly tests, but discontinuance of these tests prevented this.

"Conclusions. The tests have shown that practically all arc stations in the country can be received with ease tho signals are much weaker than on main antenna, but of particular interest is the fact that when static prevents reception on the main antenna, reception can be continued on the underground antenna. This has even been done during a severe lightning storm, when the main antenna would have been dangerous without grounding. Reception is also directional and permits of avoid-

ing interference to some extent by using a wire off-direction of an interfering station. Construction is under way for putting a conductor in terra cotta piping for comparing results already obtained with a plain buried wire. Plans are also being made for trying out the buried wires for locating a distant control station within the limits of the Naval Reservation. A point can be obtained in the southeastern corner of the Naval Reservation, which is 2,600 feet (793 m.) from the radio power house, and it is now thought possible that at this distance, reception can be carried on while the arc is in operation for stations which are on a line at right angles to the line of bearing of the power house. The long wires are being extended to a total length of 2,200 feet (671 m.). Further report will be made if any decided advantage from the additional length is observed.

"Recommendations. It is recommended that all stations in regions where static interference is encountered be equipped with underground reception wires; long wires, about 1,500 feet (458 m.) for arc reception, and short wires, about 300 feet (92 m.) for spark reception. There should be at least two directions covered in order to be able to receive best from different directions. It is recommended that these underground systems be used in conjunction with elevated antennas. With an elevated antenna, when atmospherics are favorable, greater distances can be obtained, but at the same time, when the elevated antenna cannot get business thru, due to static, such stations within the range of the underground antenna can continue their work."

These remarkably high ratios of signals to strays have not been confirmed by observations by other observers at other places. Concerning Lieutenant-Commander Loftin's conclusions, it may be stated that subsequent experiments at Great Lakes, Belmar, New Jersey, and Tuckerton, New Jersey, showed that the extent to which the ratio of signals to strays is improved by the use of the ground wires, depends upon the conductivity of the ground and that the character of the soil at New Orleans is particularly favorable. Such is also the case at Tuckerton, where the wires were buried in a salt marsh. At Belmar, on the other hand, the land wires, buried as deep even as seven feet (2.14 m.), showed very poor ratios of signals to strays on long waves, altho considerable improvement was noted on short waves. At Great Lakes two installations were made, with two different types of soil, one dry and one wet. Observations were in fair agreement with those obtained at other stations. Concerning Lieutenant-

Commander Loftin's recommendations, it may be stated that the recommendation of 300 feet (92 m.) length of wire for spark reception would be correct only for a certain kind of wire with a certain kind of insulation and at a certain fixed wave length. Later experiments at New Orleans and Great Lakes will make this point clear. The fact that the signals on underground wires are weak can, of course, be compensated for by the use of a regenerative receiver and amplification. Lieutenant-Commander Loftin points out, in another report dated June 21, 1917, that there is an optimum length for underground wires for each wave length and estimates it to be one-fifth of the wave length of the incoming signal. This is, in a way, incorrect, as later experiments showed that the ratio of optimum wire length to wave length depends upon the size of the wire and the nature of the insulation surrounding it. Under date of June 13, 1917, Lieutenant-Commander Loftin recommended that the underground system be used in the new distant control installation at New Orleans. Under date of August 14, 1917, the Bureau informed the Commandant that preliminary experiments by the Naval Radio Laboratory at the Bureau of Standards seemed to indicate that strays were largely eliminated by the use of heavily insulated wires, rather than by the use of bare wires. Lowering of the insulating resistance seemed to bring in static to a marked degree.

3. Rogers' Experiments

During the latter part of May, 1917, when the writer was District Communication Superintendent for the 9th, 10th, and 11th Naval Districts, he received orders to report for temporary duty at the Bureau of Steam Engineering, Washington, for a conference with Commander S. C. Hooper, in charge of the Radio Division of the Bureau, on the possibilities of subterranean reception of the type which had already been demonstrated to representatives of the Bureau by Mr. J. H. Rogers at Hyattsville, Maryland. Full credit is due Mr. Rogers for having first demonstrated to the Navy Department that effective reception was possible with subterranean wires, both on long and short waves. The failure of Mr. Clark to obtain more satisfactory results in 1909 is unquestionably due to the inferior detecting systems available at that time. Mr. Rogers' work had been done with audion detectors, and he succeeded in interesting the Bureau of Steam Engineering in the practical possibilities of subterranean reception on the theory that the ratio of signals to strays was superior to what would be obtained with

ordinary aerial reception. The extent to which this theory was justified will appear in the progress of this report and subsequent reports in the same series. On the morning of June 1, 1917, the writer proceeded, in company with Mr. Rogers, to his laboratory which was located on a high hill in a large isolated tract belonging to the Rogers' estate. The land is a rocky formation covered with several feet (about a meter) of reddish, sandy soil, which at the time the tests were made, was fairly dry. The surrounding country is heavily timbered. Mr. Rogers had an underground room into which leads were run from various wires which were buried underground at approximately a depth of one foot (0.305 m.) below the surface, and ran out to the North, Northeast, East, Southeast, South, Southwest, West, and Northwest. These wires varied in length from 300 to 1,000 feet (92 to 305 m.). Some were bare wires, some insulated and some were laid in tile for part of the distance. The receiving instruments used in the tests consisted of a loose coupler for long waves, a loose coupler for short waves, suitable loading coils and tickler coils, and variable condensers. The receiving bulb was a tubular audion going by the trade name of "audiotron," and seemed to be fairly sensitive. The apparatus was by no means ideal for the purpose, as certain variations in inductance, which should have been possible, could not be obtained. Tests on short waves in the neighborhood of 600 meters were made to determine whether the apparatus was directive and whether the wires laid in tile, or insulated wires or bare wires were best. Directivity was very evident, the bare wires giving greatest strength of signal. Mr. Rogers had been unable to get any tuning in his primary circuit, but the writer found, that with proper adjustments of series inductance and capacity, sharp tuning could be obtained in the primary, provided that the secondary was loosely coupled. The proper length of the bare wires for short waves was not exactly determined, but indications were that it lay between 300 and 500 feet (92 and 153 m.) for a 600-meter wave. Similar observations were made on long waves, signals from New Brunswick being received with very satisfactory audibility, the wires showing a marked directivity, altho not so much as in the case of short waves. New Brunswick's wave at that time was 8,600 meters. It was evident that a wire 1,000 feet (153 m.) long was not long enough to get the best possible signal on New Brunswick. It was not possible to make accurate observations on the ratio of signals to strays, but it appeared that the strays were eliminated more completely

on short waves than on long waves. It was not possible to copy trans-Atlantic signals on account of the strays being too violent on long waves. The wires were usually used in pairs in a straight line, one wire being connected to the antenna post of the receiver, and the other to the ground connection of the receiver. Further tests were made using a ground connection against various wires. The ground connection consisted of a pipe driven deep into the ground. Results were not very satisfactory, the directivity being less marked and the signals much weaker. In view of subsequent experiments it is evident that the ground connection was not a good one. Mr. Rogers stated that he had transmitted on short wave lengths with 0.5 kilowatt power input from a small station at his house, but had, so far, been unable to receive the signal more than a few miles away.

4. Great Lakes Experiments

As the result of this test with Mr. Rogers' apparatus, the writer recommended to the Bureau of Steam Engineering that the subterranean method of reception be given a thoro scientific investigation and that the Bureau equip a small portable laboratory at the Great Lakes Station for this purpose. This was agreed to by the Bureau, and work was immediately started upon the writer's return to Great Lakes. Considerable delay was experienced at Great Lakes in getting a portable steel building for use as a laboratory, therefore, on July 10, 1917, work was begun on two sets of buried wires, one running in an east-and-west direction and the other in a north-and-south direction, and which were installed directly under the towers for the main antenna at the Great Lakes Station. It seemed worth while to discover whether underground reception was possible in the immediate vicinity of the antenna and in proximity of a buried counterpoise. One set of east-and-west wires installed directly underneath the towers consisted of 600 feet (183 m.) of number 12 wire,* with the receiving set in the middle. 150 feet (45.8 m.) of both ends of the wire was left bare. The wires were buried three inches (7.6 cm.) deep in dry soil. Another pair of wires, consisting of bare stranded aerial wire, were similarly laid a few feet distant. A single stranded aerial wire, bare, was run in a southerly direction, down a hill into a ravine. The following results were obtained. Position reports were received from vessels east and southeast from Great Lakes, using the east-and-west receiving combination. On several occasions this was

* Diameter of number 12 wire = 0.0808 inch = 0.21 cm

possible when strays were so heavy that it was not possible to use the main antenna. The signals were, however, very weak, much weaker than the corresponding signals received at Hyattsville. Signals from the Naval Station at Ludington, Michigan, 130 miles (209 km.) northeast of Great Lakes, could not be received on any combination of wires. Signals from the Naval Station at Milwaukee, 50 miles (81 km.) to the north, were received distinctly on the east-and-west wires, but were many times weaker than on the regular antenna. Milwaukee's signals were, however, very satisfactory on the south wires used against either the east or west wire. These experiments were all on 600 meters. Arlington's 2,500 meter spark was copied without difficulty on east-and-west wires. Two additional wires, 500 feet (153 m.) long, were laid in an east-and-west direction, and various long wave signals were copied. It was possible to leave these wires connected and the receiving set in operation while sending was going on overhead on the aerial at 600 meters spark. It was not possible to continue reception on account of the loud interference, but the reaction between sender and receiver was not sufficient to cause any damage. Great Lakes had two antennas, one under the other, one with a free wave length of 500 meters and the other with a free wave length of 1,200 meters. It has never been possible to maintain the arc watch on the larger antenna while sending was going on at 600 meters on the smaller one. This indicated possibilities for distant control purposes. It was evident, however, that serious reactions were being experienced fron the overhead antennas and the buried counterpoise. On the whole, better results were obtained on long waves, using the 500-foot (153 m.) wires. Work was, therefore, started at an extemporized laboratory on the sand beach at the foot of the 90-foot (27.5 m.) bluff at Great Lakes. A tent was erected on the beach and long and short wave receivers with amplifiers were installed; and work at the radio station proper was abandoned, except on the 500-foot (153 m.) east-and-west wires which were used for the reception of long waves as soon as it was found that both Arlington and San Diego could be copied on the ground wires with greater accuracy than on the main antenna. Under date of August 14th, it was reported to the Bureau that several receiving sets could be connected simultaneously to the same pair of ground wires, without interference, and without the tuning of the primaries being in any way interfered with. In continuous wave reception, beat tones, of course, result, but unless the waves are too close together this can readily be avoided. It

must be noted at this point that the writer's experiments at Hyattsville showed that it was only possible to tune the primary when a series condenser was used. Wave meter tests made at Great Lakes showed that as far as the primary tuning was concerned, it was determined wholly by the primary inductance and the series condenser and that with wires over 100 feet (30.5 m.) in length, the length of the buried wires had practically no influence on the tuning of the primary. In other words, any ground systems beyond 100 feet (30.5 m.) in length would tune for a given wave at the same primary setting. This would seem to indicate that the ground wires themselves formed an aperiodic system. This is also checked by the fact that multiple reception is possible on long waves.

5. Experiments on the Beach at Great Lakes

The wires on the beach were 90 feet (27.5 m.) below the base of the radio towers and 900 feet (275 m.) distant from the nearest tower. The receiving set in the tent was 20 feet (6.1 m.) from the water's edge. The wires laid out first were all 300 feet (93 m.) long each way and ran approximately north-and-south. The following results were obtained. Very weak signals on short waves were received on bare wires laid in wet sand, while somewhat stronger signals were received with bare wires laid in dry sand. Better signals were received with wires which were either insulated or in dry sand for 200 feet (61 m.) and then laid in wet sand the remaining 100 feet (30.5 m.) each way. The best signals were obtained on well insulated wires laid in wet sand. A regular watch was established from 6:00 P. M. until 12:00 P. M. on August 11th, on 600 meters, using a tubular audion and a regenerative receiving set without amplification. The operator was able to copy every ship worked from Great Lakes, altho one of them was 110 miles (177 km.) to the northeast and several others were approximately 50 miles (81 km.) to the southeast. A large number of ship calls were logged, but as the log covers three pages, it is not reproduced. In two instances the operator received messages correctly upon which a repeat was asked by Great Lakes and by Milwaukee. The arc signals received from New Orleans were very strong but those from Darien were weak. This was due to the short length of wire used. It was possible to copy Arlington's 2,500 meter spark on north-and-south wires, altho Arlington's direction from Great Lakes is much more easterly than southerly. It is noteworthy that Arlington's weather reports and "press" were copied with-

out the least difficulty altho Great Lakes, 900 feet (275 m.) away, was operating on the 600 meter spark thruout the press work. It was also possible to copy Milwaukee, 50 miles (81 km.) to the north, on 600 meters, while the Great Lakes arc was in operation on 6,000 meters, radiating 50 amperes. In order to utilize the directivity of the ground wires in such a way as better to eliminate the interference from Great Lakes, the tent with the apparatus was moved 300 feet (93 m.) further to the north, so that a line from the main radio station to the beach station would bisect the wires nearly at right angles. Wires 300 and 600 feet (93 and 183 m.) long were laid in wet sand and a regular spark and arc watch established on the beach. The wires were buried about a foot (0.3 m.) deep. The following table of observations is typical of the results obtained and shows that when Great Lakes (NAJ) was sending on 1,500 meters only 900 feet (275 m.) away, no serious interference resulted on 600 meters. None of the stations observed were of high efficiency, the average radiation not being over 7.5 amperes and the average height to center of capacity about 125 feet (38 m.).

Time	Station	Distance	Audibility
10:50 A.M.	WME	50 miles (81 km.)	5,000
10:54	WLD	130 miles (209 km.)	50
10:56	WFK	175 miles (282 km.)	50
11:25	WDC	Unknown	500
11:37	WDI	35 miles (56 km.)	1,000
11:40	WFX	40 miles (64 km.)	100
11:42	NAJ	900 feet (275 m.)	400
11:43	WHW	120 miles (193 km.)	125
11:45	WLD	130 miles (209 km.)	100
1:45 P.M.	WFE	35 miles (56 km.)	600
1:50	WFH	35 miles (56 km.)	700

As far as handling regular traffic was concerned, the station on the beach was able to do much better work than the regular station, owing to the elimination of strays and to the ability to work thru storms during which the main antennas had to be grounded. Iron pipe ground connections were driven into wet sand at the end of the wires and while various stations were sending the ends of the wires were connected to the pipe. No difference in signal was noted. The strays were slightly worse. The

directivity of the wires on the beach was very marked, signals from the "Essex," distant only two miles (3.2 km.) straight east from the beach station, were received with an audibility of only 2.5. On the other hand the Naval Station at Manistique, Michigan, 265 miles (427 km.) straight to the north, came in at the same time with an audibility of 400 on the same wave length. When the "Essex" moved away to the south, the signals came up gradually in intensity. Simultaneous reception on arc and spark, with the same pair of 300-foot (93 m.) wires was carried on without difficulty or mutual interference.

Tests with Multiple Wires. The addition of two wires on each side separated several feet (about a meter) from the original wires and of the same length, produced no noticeable change in the signals or strays. This point has subsequently been tested many times. The Great Lakes results do not agree on this point with those reported earlier by New Orleans, but it is certain that the use of multiple wires of the same length offers no material advantage.

6. Experiments by the Naval Radio Laboratory

During the summer of 1917, the experiments of Mr. Rogers at Hyattsville were investigated by Doctor L. W. Austin of the Naval Radio Laboratory, Bureau of Standards, and additional experiments were made under Doctor Austin's direction by Lieut. J. L. Allen, Chief Electrician Nicholson, and Electrician Parks at Mr. Rogers' laboratory at the Fish Hatchery near Hyattsville. Wires were run for some distance overland and then into two small lakes. Observations were made on the Eiffel Tower signals, which were continuous wave at 8,000 meters. The signals were weak but perfectly readable with practically no strays, altho at the same time heavy strays were reported at the Laboratory at the Bureau of Standards. At other times, however, the strays were extremely bad. Doctor Austin reported that it seemed likely from the results at the Fish Hatchery as well as from those at the Rogers' station, that severe strays on ground wires might be connected with the drying out of the ground in the hot sun after a rain. Experiments by the Naval Radio Laboratory at Mr. Rogers' Piney Point Laboratory made in the latter part of August and the first part of September dealt entirely with long wave work. They will be reported in a subsequent paper. Of special interest here, as applying also to short waves, is the

fact that they emphasize the importance of adequate insulation and the desirability of having the wires wholly under water or in moist ground, thus checking experiments which were simultaneously being carried on at Great Lakes.

7. Optimum Wire Length

The New Orleans' experiments having indicated that for best results on short waves, the length of the wire should be carefully chosen, experiments were begun on September 1, 1917, at Great Lakes, to determine the optimum wire length for different wave lengths. The first work was done on 600 meters. The wire used was number 12 rubber covered.* Switches were installed at various points along the wire which was 300 feet (93 m.) in length each way, north-and-south, and audibility measurements were taken with various stations sending and a curve was plotted the vertical ordinates of which represented the audibility of the signal at a certain length of wire, compared with the audibility of the same signal on a comparison wire with a fixed length of 100 feet (30.5 m.). The observations were made on Milwaukee, Manitowoc, Manistique (all nearly straight north of Great Lakes), and Frankfort, and Ludington (which lay to the northeast). The curves all show a very sharp maximum at 125-foot (38 m.) length of wire. The optimum length evidently does not depend upon the direction from which the signal comes. Experiments on optimum wire length were continued, and continuous watch was established on the optimum wire length for 600 meters. It was found possible to receive all stations in the Great Lakes district as far as Alpena in the daytime and as far as Calumet at night. Calumet is 335 miles (539 km.) distant. The strays, as a rule, were practically absent. Occasionally loud cracks, widely separated, were received. These isolated strays, altho loud, did not interfere with the reception of signals on account of their brief duration. On two occasions, strays rose to an audibility in excess of 5,000, using two stages of amplification, but even in this case reception of signals, altho a little difficult, was not interrupted, as the strays were not all numerous. On these two occasions it was necessary to ground both the antennas at the main station. When the optimum wire length is used, it is very important indeed that the wires be fully insulated, since grounding of the wire, either intentionally or accidentally, produces a diminution of the signals. If the wires are accidentally grounded at both

* Diameter of number 12 wire = 0.0808 inch = 0.21 cm.

ends, the signals is reduced 50 per cent. of its maximum value. Grounding the wires intentionally or accidentally, decreases the ratio of signals to strays. The decrease is particularly marked when the wires are carefully adjusted to optimum length. For short waves, the length should be within 5 per cent. of the optimum value for the best results. In order to determine whether the optimum wire length was proportionate to the wave length, arrangements were made for the transmission of test signals from the University of Wisconsin radio station, 9XM, using wave lengths of 425 and 1,125 meters. The bearing of 9XM is 30° north of west from Great Lakes, and is 90 miles (145 km.) distant. The optimum length for 425 meters turned out to be 87 feet (26.5 m.) each way, or 174 feet (53 m.) over all which is almost exactly $\frac{1}{8}$th of a wave length. The optimum wire length for 1,125 meters proved to be 202 feet (61.6 m.) each way or 404 feet (123.2 m.) over all, which is $\frac{1}{10}$th of a wave length, but inasmuch as an insufficient number of observations were taken at the peak of the curve, it is likely that further observations would show this value also to be $\frac{1}{8}$th of a wave length. The length found for 600 meters, 125 feet (38 m.) each way or 250 feet (76 m.) over all, is very approximately $\frac{1}{8}$th of a wave length. The shape of the curves determined at Great Lakes indicated a rather abrupt rise of signal strength when the optimum wire length was secured. The curve is, however, flatter for 1,125 meters than for 600 meters; and subsequent experiments on waves in excess of 5,000 meters, and with very long wires, have failed to show any pronounced optimum wire length. Inasmuch as it was suspected that the optimum length depended upon the electrical constants of the surrounding medium, wires were installed at the beach station directly in the water, which in this case was, of course, fresh water. The optimum length turned out to be exactly the same, somewhat to the writer's astonishment, but the signals were nearly 20 times as strong as when the wires were laid in dry sand. Very satisfactory signals were obtained using two wires, one connected to each post of the receiver and both running in the same direction, provided the one wire was in the water or in very wet sand and the other was in dry sand. The waves evidently experience a change of phase as well as a change in their angle of stagger or inclination with the horizontal. Experiments were now undertaken by Ensign A. Crossley, at Great Lakes, under the writer's direction, to determine whether the optimum length depended upon the size of the wires and the thickness of the insulation. It

seemed highly desirable to use high tension insulation for a permanent installation and experiments were undertaken, first with number 14 high tension Packard cable,* for which the optimum wire length was considerably longer, being in the neighborhood of 200 feet (61 m.) for 600 meters. These experiments continued thruout the summer, and Ensign Crossley was able finally to report that the optimum length was inversely proportional to the capacity per unit length of the wire measured against the ground. In other words, with a given size of wire, the thicker the insulation the longer will be the optimum length, and with a given thickness of insulation, the larger the wires, the shorter the optimum length. These observations are very difficult and a matter of much labor to obtain. It is to be regretted that more of them are not available, made by other observers, for checking-up purposes. The optimum wire length for wires laid in reddish clay soil of the bluff turned out to be the same as was previously determined on the beach, nevertheless it was evident that the capacity per unit length of a wire laid in very dry soil is less than when it is laid in very wet soil, therefore, the optimum length should depend on the nature of the surrounding soil. In order to get an extreme case, wires were laid 3 inches (7.62 cm.) deep in very dry sand on the beach and after many failures on account of frequent rains, a series of measurements were taken which indicated pretty definitely that the optimum length for 600 meters for number 12 rubber covered wire† was 162 feet (49.4 m.) each way instead of 125 feet (38.1 m.) each way. It is evident, therefore, that for best results wires should be laid in fairly wet soil or in water. First, because the signals are much louder; second, because the relative suppression of strays is greater, and third, because then the optimum length will remain fixed. If the wires are laid in salt water, care must be taken not to have them too deep unless conditions are such that very high amplification can be used. The signal falls off very rapidly with the depth in salt water, but in fresh water there is, on long waves at least, no measurable falling off in signal strength down to 60 feet (18.3 m.) in depth. The existence of the optimum length is very helpful in making the system much more sharply selective, a feature which is particularly valuable in distant control work. Figure 1 shows two typical curves obtained in a determination of optimum wire length for number 12 simplex cable, the signals in each case being com-

* Diameter of number 14 wire = 0.0641 inch = 0.16 cm.
† Diameter of number 12 wire = 0.0808 inch = 0.21 cm.

pared with those received on 125 feet (38 m.) of rubber covered number 12 wire. It will be noted that 125 feet (38 m.) was the optimum length for number 12 rubber covered wire. The insulation of the simplex cable is approximately twice as thick as that of the number 12 rubber covered, and it will be seen from the curves that the optimum length is also twice that of the rubber covered wire. It will be noted also that when the opti-

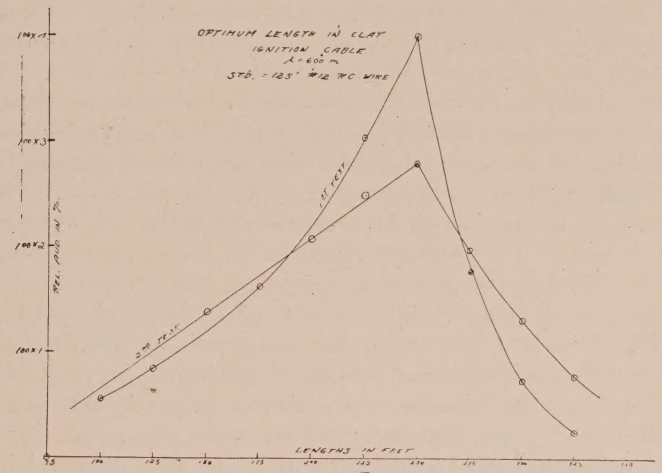

FIGURE 1

mum length is used for each wire, that the intensity of the signal is four times as great on the simplex as it is on the rubber covered. Simplex cable has therefore been used in the final installation, both at Great Lakes and at Norfolk. The optimum length for any given sample of wire may be predetermined approximately by measuring the capacity per unit length of the sample immersed in water and comparing it with the capacity per unit length of a standard wire the optimum length for which is already known. The optimum length of the sample will be related to the optimum length of the standard wire inversely as their capacities per unit length. This holds good, as has already been pointed out, only when the wire is buried in fairly moist soil or in water.

8. Experiments on the Bluff at Great Lakes

The steel building intended for the radio laboratory having been installed in Camp Paul Jones, one-quarter mile (0.4 km.)

straight north of the radio station, wires were laid in trenches four feet (1.2 m.) deep, it being evidently desirable to get down to the level of permanently moist ground for the sake of getting stronger signals and good ratios of signals to strays. Previously determined optimum lengths of wire were used for 600 meters. The trenches radiated north, east, south, and west. A good ground connection was made by driving an iron pipe down to ground water level. It seems curious that ground water should have been found below four feet (1.2 m.) at the location of Camp Paul Jones as it is near the edge of a 90-foot (27.5 m.) bluff, but such was the case. In ground wire work it is, of course, always possible to use one wire against a good ground connection. It has never been definitely settled whether this gives as good elimination of strays as when the wires are used in pairs in the same straight line. The signal is about 65 per cent. of the strength of the signals which are obtained when the wires are used in pairs. The optimum length is the same. If additional wire is added to the ground wire system, but is not buried or under water, it has very little, if any, effect upon the optimum length. That is to say, the optimum length is the length of the submerged or subterranean portion of the wire. If, as Ensign Crossley's reports indicate, the optimum length is determined by the capacity per unit length of the wire, this is, of course, fairly understandable, as the portion of the wire unburied has relatively small capacity. Since the ground wire system is highly directive, the best standard listening-in arrangement for picking up signals is to use a pair of wires at right angles to each other, with a switch arrangement so that when a signal is found, the proper wire pair can immediately be thrown in. The use of a west wire and south wire, for instance, will pick up signals from stations lying in a general north-and-south direction, or in a general east-and-west direction. Signals coming exactly along the bisector of the angle between the two wires, however, will be eliminated. The best universal listening-in arrangement is to use two wires at right angles in parallel with each other connected to one side of the receiver, the other side of which is grounded.

9. Experiments at New London

During the month of August, 1917, underwater experiments were conducted by Mr. H. H. Lyon at the Submarine Base at New London, Connecticut. The water at this point is brackish. The experiments were mostly on long waves and only a relatively

small amount of data was collected. This showed, however, that the results parallel those obtained at other points. It was noted in a report by Mr. Lyon under date of August 11, 1917, that it was possible to work thru a thunderstorm which appeared to be only three miles (4.8 km.) distant and that it was highly desirable to have the wires fully insulated. It is understood that signals were received up to fifteen feet (4.6 m.) under water, altho this point is not specifically mentioned in this report. One stage of amplification was used thruout the experiments. The antenna wires were 500 feet (153 m.) in length.

10. Transmission on Ground Wires

The failure of the early experiments by Mr. Clark on transmission using submerged wires has already been pointed out as having been due to inadequate detecting apparatus. Mr. Rogers' experiments on transmission were far more promising. The problem was taken up again by Ensign A. Crossley under the writer's direction. The following excerpts from Ensign Crossley's reports under date of January 9th and January 23, 1918, are of interest here.

"It is noted that the use of a series condenser and large inductances are essential. By using the ground and one wire, a wave is emitted whose directive transmitting properties are impaired, while by using two wires the directivity of this system is very pronounced; namely, if we use a ground and south wire, signals are received with a maximum audibility at the radio station which is due south of the laboratory, and if the east-and-west wires are used, we find that minimum audibilities are received at the radio station. Altho comparatively low voltages (1,500 to 5,000) were used on the subterranean wires and no trouble was experienced with their insulating qualities, it is practical to use other systems which necessitates higher voltages, provided slight changes are made to insure sufficient insulation. The foregoing experiments were conducted on wires whose optimum length gave maximum received signals on a 600-meter wave. It may be probable that there is a different optimum length for transmitting on 600 meters, but experiments for this optimum length are impractical at the present time due to frozen ground in this vicinity. Experiments of this nature will be conducted in the Spring."

"Much trouble was experienced in operating the 0.5-kilowatt bulb transmitter, due to frequent polarization of the bulbs. This trouble entailed a delay of five days during

which time different experiments were conducted for maximum radiation. Direct connection to ground wires, using inductance and a capacity in series with one wire, the other side of the circuit being connected directly to ground, gave maximum radiation, but unstable adjustment of bulbs. The main trouble with this hook-up is that when maximum radiation is obtained, the bulbs become unstable and frequently polarized. This polarization necessitates complete re-adjustment of the circuits and consequent loss of from ten to fifteen minutes of time. The inductive coupling as shown in Figure 2, gave approximately 0.5 the radiation, as obtained with the first hook-up. This connection required very accurate tuning of

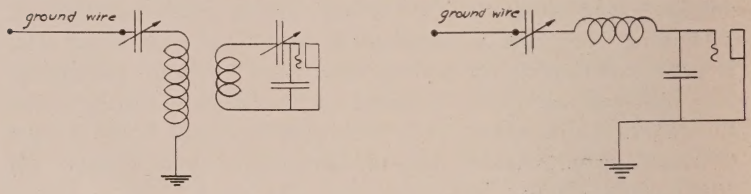

FIGURE 2

condenser before any radiation was obtained. Upon completing these preliminary tests, arrangements were made with Mr. A. L. Howard, of Chicago, who kindly offered the services of his station to conduct tests between the Laboratory and Chicago. One operator was detailed from the Laboratory to assist in overhauling Mr. Howard's receiving station. One afternoon was required to complete this work. That evening the experiments were commenced with Mr. Howard's station, 36 miles (58 km.) from Great Lakes. Wave lengths of 340, 600, and 720 meters were used in this experiment, with respective antenna currents of 0.8, 1.0, and 1.4 amperes. Considerable difficulty was experienced at Mr. Howard's station due to the audion detector being apparently dead from poor vacuum. Two hours were consumed in reviving this detector, after which time the receiving set was in perfect condition. The signals from the Laboratory were heard during the last five minutes of the test. The sending schedule being finished, no further signals were received from the Laboratory. No definite data could be obtained during this test. Arrangements are being made whereby one operator will be detailed permanently at Mr.

Howard's station and daily tests will be conducted between the two stations. If it were possible to use a Cutting and Washington or a Clapp-Eastham 'Hytone' transmitting set, both of which use low voltages, it is probable that better results might be obtained, as the bulb set is very unstable and requires expert manipulation. Efforts are being made to obtain such a set. If this is not possible a Navy portable 500-cycle field set will be used."

Under date of January 31st, Ensign Crossley reported subsequent experiments using the same combination of apparatus, except that the signals from the underground system were compared with those obtained by using the same transmitter on a four-wire antenna 200 feet (61 m.) long, 10 feet (3.5 m.) high at one end and 25 feet (7.6 m) high at the other. A wave length of 720 meters was used on the antenna and the antenna current was 1.8 amperes. On the underground system two wave lengths were used, one of 450 meters and the other of 550 meters. The radiation of the underground system was kept at about 0.5 amperes for each wave. The test was continued for one week, two hours each day. Upon averaging the audibilities of received signals, it was found that the subterranean wires emitted signals that were received at Chicago, distant 36 miles (58 km.), with twice the audibility of the signals from the antenna. The following week the experiments were repeated and showed an average audibility of 1,656 for the subterranean wires and 700 for the aerial. To test the directivity, signals were transmitted on a combination of ground and south wire, and ground and east wire. The results showed that signals transmitted on the ground and south combination were six times as strong as the signals transmitted on the ground and east wire combination. The receiving station in Chicago was due south from the laboratory. So much trouble was experienced with the bulb set that it was replaced with a Clapp-Eastham 0.5-kilowatt "Hytone" transmitting set. While experimenting with this set, it was noted that the addition of extra wires increased the radiation. For instance, if 0.8 of an ampere was obtained by using the ground against a south wire, this was increased to 1 ampere if a north wire was added. When using all the wires, namely, north, northeast, east, southeast, south, southwest, west, and northwest against the ground, a radiation of 1.6 amperes was obtained on 450 meters. The following readings were obtained at Chicago:

Combination	Radiation Amperes	Audibility of Received Signals	Wave Length Meters
Ground with south wire....	0.8	12	450
Ground with north and south wire.....	0.8	20	450
Ground with N, NE, E, SE, S, SW, W, NW.....	1.6	80	450
Regular antenna.....	1.6	60	450

The results indicated in this table are very abnormal. For instance using a north-and-south wire, nothing should have been received at Chicago except that due to a regular antenna effect, due to the fact that the true ground was a few feet (about a meter) below the level of the ground wires. The signals received at Chicago on this combination should have been very small. It later transpired that the south wire had been punctured by the higher voltages of the Clapp-Eastham set. What we had to deal with here was probably a loop transmission effect with the loop underground. The north buried wire constituted the top of the loop and the ground constituted the return or under side. The writer suggested that a counterpoise wire 2.5 feet (0.76 m.) above the ground be tried out against the north wire. This proved to give the best results, possibly due partly to the fact that less strain was placed on the insulation between the buried wire and ground. No ground connection was used with this combination. The signals as received at Chicago were 2.5 times as strong as those sent from an antenna 240 feet (73 m.) long, 9 feet (2.7 m.) wide, 14 feet (4.3 m.) high at one end and 40 feet (12.2 m.) high at the other end, using the same radiation. Ensign Crossley recommended that to obtain more radiation the use of several parallel wires would be of advantage. He was unable to try this out on account of the ground being frozen at the time. It was discovered that the combination using all wires together against the ground had very poor radiating qualities when all wires were properly insulated. During the following week, both the north and south wires again developed a ground, but it was still possible to use them against the counterpoise. The signal was reduced to one-third of its previous value. Experiments were then made with various elevations of the counterpoise above the wires in the ground with

which it was used. It was discovered that the closer the counterpoise was kept to the earth, the greater were the audibilities obtained at the Chicago station, and upon laying the counterpoise directly upon the surface the best results were obtained. Further experiments on transmission were here interrupted by the transfer of Ensign Crossley to Norfolk to undertake the installation of the subterranean distant control station at that point. The writer had already been at Belmar for some time; moreover, the weather at Great Lakes was such as to make it very difficult to continue the experiments.

11. Summary

(a) The history of the Navy's connection with ground wire work, based on the Rogers system, has been briefly outlined.

(b) It has been shown that it is possible to receive very efficiently signals from stations at any wave length, long or short, using submerged or subterranean wires, provided that one or two stages of amplification be used.

(c) The directivity of the wires has been carefully examined and it has been proven that signals coming at right angles to a given wire pair are excluded, while signals coming parallel to the wire pair are received with maximum intensity.

(d) The feasibility of utilizing this system with its highly directive and highly selective properties for distant control work has been demonstrated. A new type of distant control is therefore possible, a type where the control station need be removed only a few hundred feet (50 or 100 m.) from the sending station.

(e) The optimum wire length has been determined to be independent of the angle from which the signal comes and to be, for short waves, roughly proportional to the wave length. The existence of the optimum length greatly increased the selectivity of the receiver. The optimum length has been determined to be independent of the nature of the surrounding medium, if the same is wet or moist. The optimum length depends inversely upon the capacity per unit length of the wire used.

(f) The importance of adequate insulation has been indicated.

(g) The relative advantage of ground wire reception on short waves lies in the ability of the receiving operators to continue to copy messages thru violent storms without danger to themselves and with little or no interruption of traffic. The very great advantage in the suppression of summer strays is noted on all waves but particularly on short ones. The manner of the suppression of strays seems to be not only a reduction in

intensity all around, but a remarkable reduction in the frequency of the strays. Altho the ground wire system appears in many respects to be aperiodic, the fact that an optimum length of wire exists for short waves, stands as a hitherto unexplained contradiction.

(h) Reception in fresh water or wet soil is enormously superior to that of bare wires above or on the surface or in dry soil. As the wire is lowered into water or into wet ground, the signals increase, whereas the strays are reduced. How deep the wires may be buried with advantage is not yet known.

(i) Preliminary experiments on transmission with subterranean wires have shown that transmission with low powers and continuous short waves is possible over considerable distances. The greatest communicating distance obtained was between Great Lakes and Chicago, a distance of 36 miles (58 km.), with 0.8 of an ampere in the underground wires. Interesting possibilities are indicated by these transmission experiments. With specially insulated wires and amplifying receiving sets, much greater distances can undoubtedly be obtained.

12. Theoretical Considerations

Since ground wire reception may be carried out with wires very near the surface of the ground, altho not so successfully as when buried deeper, the phenomenon must depend upon the well known stagger or inclination of the advancing wave front, thus giving a horizontal component to the electric vector parallel to the receiving wires. It is likely that this angle of stagger increased with the penetration of the wave, especially when that penetration reaches a soil of considerable conductivity in comparison with absolutely dry soil. It is possible, of course, that buried wires may also act in a way like loops, the capacity of the wires to the ground furnishing a return thru ground for the lower side of the loop. Reception on ground wires follows the same law of diurnal variation and seasonal variation as reception on an ordinary antenna. It is not believed, therefore, that we have here to do with a separate wave or current in the earth. This point has not been specifically mentioned in this paper, but has been thoroly proven by observations on trans-Atlantic work. The writer is unable to form an opinion as to whether the suppression of strays is due to the material surrounding the wire acting like a Dieckmann cage or to the fact that possibly the origin of the strays is at such a point that their horizontal electrical components are relatively less than those

of the signals. The aperiodicity of the wires is also unquestionably an important factor in eliminating strays. Since the signals received on ground wires are admittedly much weaker than those received on antennas of comparable dimensions, it is evident that transmission on ground wires will be limited in efficiency by the low radiation in horizontal directions. It has, however, the advantage of high directivity, and as shown by Great Lakes experiments, is on low powers, decidedly more efficient than transmission on closed loops. The transmission experiments have hardly progressed to the point where any definite conclusions may be drawn.

SUMMARY: After an historical review of the work of the United States Navy with underground and underwater receiving systems, the author gives data demonstrating the possibility of effective reception on such systems, particularly when using amplifiers.

These systems are found to be directional toward waves travelling parallel to the length of the wire pair. This directional selectivity, which is marked, is applied in control stations for duplex working.

For such underground systems, an optimum wire length for best reception is found to be roughly proportional to the wave length (for short waves) and independent of the direction of approach of the signal. The existence of this optimum length gives further utilisable selectivity. This length is independent of the nature of the surrounding medium and varies inversely as the capacity per unit length of the wire. The wire in question must be well insulated.

Reception thru violent storms, and suppression of summer strays (particularly at short wave lengths) are found.

It is found that lowering such wire systems from above ground into wet soil or into water greatly increases the signal strength and diminishes strays.

Transmission at short wave lengths, over considerable distances, using such systems has been found possible with low power sustained wave transmitters.

DISCUSSION

Julius Weinberger (by letter): There has been a good deal of work done along the lines indicated in Commander Taylor's paper, by Kiebitz, Mosler, Hausrath, and Braun, in Germany, a great many years ago. Kiebitz experimented mainly with low horizontal antennas and wires laid upon the ground; his results are given in "Jahrbuch der drahtlosen Telegraphie," volume 5, page 360 (1912), and volume 6, pages 1 and 554 (1912). Of interest also is a discussion between Mosler, Burstyn, and Hausrath, in the same periodical, volume 6, pages 359-366 and 570-573 (1912), in which numerous experiments are described to prove the feasibility of reception on horizontal antennas on dry sand, over fresh water and under its surface; the fact is also mentioned that at that time Professor Braun was conducting experiments on subterranean reception in the fortress of Strassburg.

A. Hoyt Taylor (by letter): I think it must be conceded that the first papers on ground wire work appeared in Germany, altho there is evidence to show that Mr. Rogers in this country was probably working along these lines at an earlier date. The German experiments were more largely concerned with very low antennas, rather than with antennas under the earth or under the water, and no systematic attempt seems to have been made to do very long distance work or to investigate the relation between strays and signals.

SIMULTANEOUS SENDING AND RECEIVING*

By

Ernst F. W. Alexanderson†

(Consulting Engineer, General Electric Company)

The first part of this paper dealing with duplex telephony and the "bridge receiver" was printed before America's participation in the war, but the publication of the same was withheld at the request of General Squier and Commander Hooper after a demonstration of the system to these officers in Schenectady. The author also had the opportunity to make a demonstration of the bridge receiver on the battleship "New York" in accordance with the request of Commander Hooper; and it is his understanding that further applications of the system of simultaneous sending and receiving to war ships have been made by the Navy.

The object of this development was briefly to provide means for neutralizing the overwhelming intensity of the transmitted signal so as to make the receiving set sensitive to the faint impulses of the distant signal. Popularly speaking, the corresponding equivalent in sound waves would be to have an ear which could be so adjusted that a person could stand close to a steam whistle without hearing the whistle but listen to a person speaking from a distance of a few hundred feet (about a hundred meters). A successful solution of this problem was found as described. This method of reception which is characterized by a static bridge neutralization may be properly classified as the "bridge receiver."

The Barrage Receiver

During the war the same problem presented itself again in a form which called for a new solution. Distances are only relative, and a steam whistle located in Germany might make

* Received by the Editor, February 8, 1919. Paragraphs and figures starred thus: *, were received March 14, 1917. Presented before the Institute, New York, April 2, 1919.

† In connection with the experimental work referred to in this paper, the author wishes to acknowledge the co-operation of Mr. H. H. Beverage and Mr. B. Bradbury.

such a noise that it would completely drown out both in England and France the sound of the voice calling from America. To find a way to counteract such a contingency was seriously considered by the Inter-Allied conference in February, 1918; and appeals for a solution were conveyed to the author by the French representative in this country, Lieutenant Paternot. The solution to this problem which was adopted by the American as well as the French Government after the first demonstration, has become known as the "barrage receiver." This name appears appropriate because the word "barrage" has not only the military meaning which has become so familiar but also the original meaning of toll or stoppage prevention. Thus the barrage receiver may be used not only in time of war to counteract the offensive barrage of an enemy radio station, but it may be used to multiply the number of peaceful communications that may be carried on simultaneously without disturbing each other.

Duplex Radio Telephony

*Everybody who has experimented with radio telephony has undoubtedly observed that the interchange of ideas is not satisfactory if it is necessary to manipulate a switch of some kind in order to change the equipment from sending to receiving. Even if an automatic device is used for performing the change-over, the two parties are apt to say "hello" simultaneously, then wait for an answer simultaneously, then say "hello" again, and finally give it up in despair. It can, therefore, be said that one of the most important problems from the point of view of making radio telephony practical and useful for the general public is to devise a simple method of duplex operation, whereby the speaker is able to hear the voice of the other party in the same way as this is done on the wire lines. In the work that has been done to attain this end several possibilities have presented themselves and have been tried out. It should first be mentioned that Fessenden worked out a system of duplex telephony whereby the same antenna could be used for sending and receiving at the same time. As shown by the patent records, this was accomplished by a system of neutralization in the receiving circuit whereby a high degree of selectivity is attained between the sending and receiving wave lengths. In deciding upon the possible methods of attacking the problem experimentally the above method was left out of consideration on account of the practical difficulties that it appeared to present.

*The first method that yielded practical results was the use of separate sending and receiving antennas, located sufficiently far apart, so that the selectivity of ordinary receiving instruments could be depended upon for differentiation between the wave lengths of the sending and receiving stations. Each pair of sending and receiving stations were interconnected by a wire line and furthermore connected to the exchange of the local telephone system, so that any subscriber on the telephone system could be connected to the radio system. With this arrangement the radio system has the same relation to the subscriber as a toll line. The radio operator takes the place of the toll line operator, and to the subscriber the method of communication is the same as a conversation over the toll line. The diagram of connections is shown in Figure 1. It may be noted that the lines from the sending and receiving stations are introduced in series with the subscriber's line. While a shunt connection can be made which

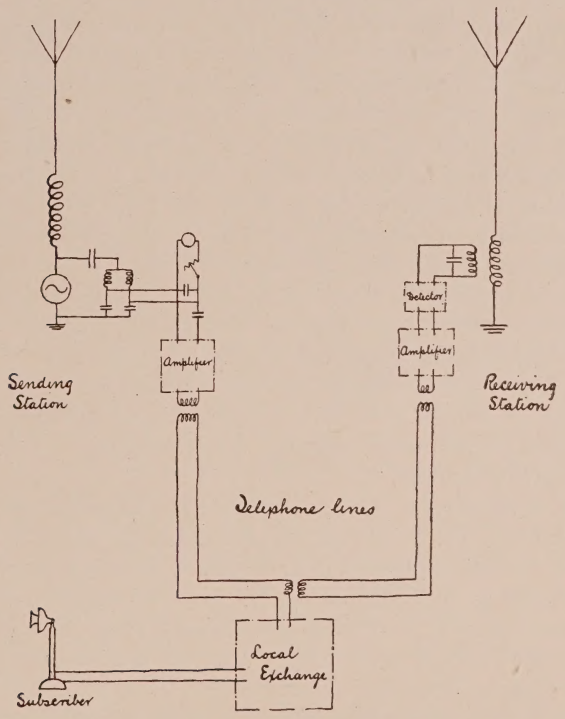

*FIGURE 1—System of Duplex Radiotelephony Connected with Local Telephone Exchange

is theoretically equivalent to a series connection if resistance, inductance, and capacity are carefully equalized, it was found that the series connection could more easily be arranged so as not to interfere with the quality of articulation. The subscriber and the sending station are connected like two ordinary subscribers on a central exchange with the only difference that a transformer with its primary winding connected across the line from the receiving station is, by its secondary, permanently introduced in series with the line to the sending station. A telephone current originating in the receiving station is thus transformed into a current flowing in the closed circuit between the subscriber's instrument and the instrument in the sending station. A telephone current originating in the subscriber's instrument will follow exactly the same path. It thus follows that the current originating in the receiving station will be transmitted by the sending station in the same way as the current carrying the voice of the local subscriber. Consequently both sides of the conversation are transmitted by each sending station and a third party might hear both speakers by tuning in on either of the two wave lengths; this conclusion was confirmed by the tests. Another conclusion can also be drawn from the above reasoning. If the amplification in the receiving station should be made great enough to produce a telephone current in the subscriber's line of greater intensity than the current originally produced by the speaker, this same current will be relayed again thru the sending station and come back to the speaker in intensified form and would again be transmitted from the first sending station. A cumulative effect would thus be created which would result in self-exciting inarticulate oscillations such as may be obtained by holding a receiver in front of a microphone. Any trouble from this source is entirely avoided by keeping the amplification within a certain critical value, whereby the retransmission becomes so rapidly converging as to cause no noticeable interference.

*While the system of duplex radio telephony described will probably prove the most practical for communication over long distances between subscribers of the local telephone exchanges, there are other promising fields for radio telephony for which interconnection with wire telephone exchanges is neither desirable nor practical. Such applications are communication between ships, emergency communication between sub-stations of electric power systems, radiotelephonic train dispatching, supervising stations for forests, and, in general, communication between

isolated settlements in unbroken countries. In all these cases, it is essential that the sending and receiving equipment should be a unit controlled by the same operator. There is, on the other hand, no object in combining the transmitted and received telephone current in the same circuit because the operator may speak into a microphone and receive thru a headphone which two instruments have no electrical connection with each other. The most desirable arrangement under these conditions would, no doubt, be to have a duplex system as indicated by Fessenden, whereby the same antenna could be used simultaneously for sending and receiving. Another possibility of using the same antenna was considered: to use the same set of wires as a loop antenna for the one function and as an open antenna for the other function. For various reasons, however, the following solution, which will be described in greater detail, was found the most practical.

Neutralized Receiving Antenna Mounted on the Same Mast as the Sending Antenna

*If two sets of wires are mounted on the same masts, the radiation from one set to the other is obviously so strong that the overpowering of an ordinary receiving set by the transmitted energy would be almost of the same order of magnitude as if the identical wires were used. The quantitative relations may be better appreciated by mentioning specific figures. In the tests made in Schenectady, the receiving antenna consists of five wires mounted as an umbrella around the main mast, while the sending antenna consists of two wires extending from this mast to another building. The capacity to ground of the sending antenna is 0.003 microfarad, the receiving antenna 0.0011 microfarad, and the mutual capacity such that 10,000 volts on the sending antenna produces 500 volts on the receiving antenna when it is disconnected. While it is obvious that an antenna oscillating with 500 volts continuous waves could not be used with ordinary methods of reception, the system for neutralization which will be described has proven so effective that an ordinary receiving set can be used for receiving signals from such distances as the Pacific coast (2,500 miles or 4,000 km.) without any appreciable interference from continuous wave radiation from the main antenna of 20 amperes and 10,000 volts.

*Two methods of neutralization have been used: inductive neutralization and static (capacitive) neutralization. While both methods have been used successfully, the capacitive

neutralization is much preferable both on account of accuracy of adjustment and simplicity. A diagram of inductive neutralization is shown on Figure 2. The transformer *T* is used to create a potential of opposite phase to the potential of the sending antenna. The negative potential thus created is transferred to the receiving antenna thru the exposure condenser *E*. The

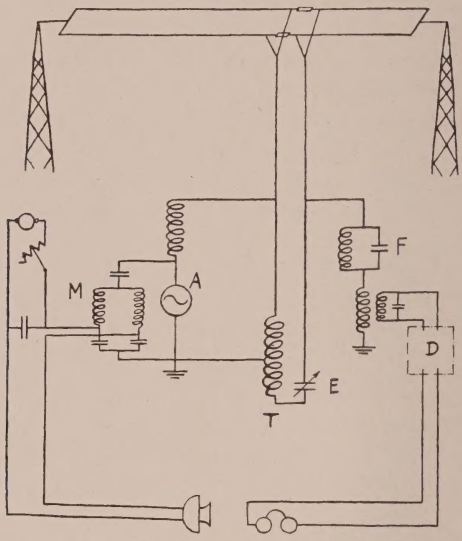

*Figure 2—System of Duplex Radiotelephony with Inductive Neutralization

M—Magnetic Amplifier
A—Alternator
T—Neutralization Transformer
E—Exposure Condenser
F—Frequency Trap
D—Detector

negative potential thus impressed upon the receiving antenna thru the transformer and the exposure condenser is adjusted so as to counterbalance exactly the direct exposure from antenna to antenna, thus leaving the receiving antenna at ground potential. The phase relation of the transformer is, however, not exactly 180°, and a residual potential is left on the receiving antenna which is sufficient in most cases to interfere with reception unless further precautions are taken. If, however, a frequency trap *F* is introduced the neutralization becomes good enough so that an ordinary receiving set can be used.

The arrangement shown on Figure 2 was used to demonstrate duplex radio telephone conversation between Pittsfield and Schenectady (50 miles or 80 km.)

The Bridge Receiver

The system of capacitive neutralization is shown diagrammatically on Figure 3. The receiving antenna, A_2, is connected thru a shielded primary loading coil, T_2, to a counterpoise condenser, C_3. This loading coil is coupled aperiodically to the secondary of a receiving set of any ordinary type. The counterpoise condenser is connected thru the exposure condensers C_1 and C_2 to the sending antenna.

The function of the capacitive neutralization can be best explained by showing the diagram as a Wheatstone bridge as in Figure 4. The exposure condensers and the counterpoise condensers form an artificial circuit duplicating the potential drops between the sending antenna, the receiving antenna, and ground. By adjusting the exposure condenser two equipotential points are found between which the receiving set is connected in a manner analogous to the Wheatstone bridge, hence the name "Bridge Receiver."

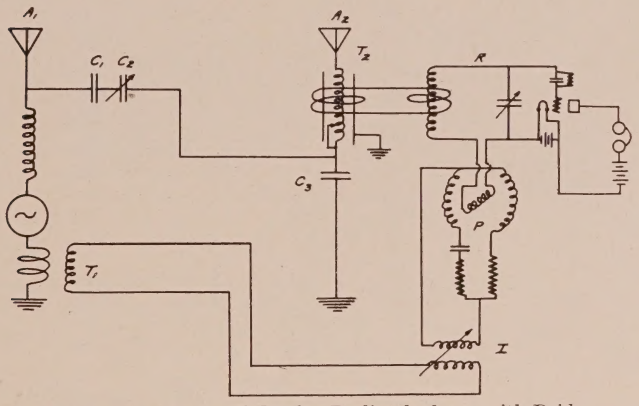

Figure 3—System of Duplex Radiotelephony with Bridge Receiver (Capacitive Neutralization)

*The neutralization by this method is so sharp that the influence of the two antennas on each other is reduced much below other sources of disturbance. The principal remaining disturbances caused by the transmitting system are the magnetic strays within the building. In so far as these strays are in phase with the antenna radiation, they are automatically taken care of in neutralizing the antennas. When neutralization is made for minimum disturbance, the neutrali-

zation effect is adjusted so as to compensate the sum of the outdoor and indoor radiation. However, in so far as the indoor strays are out of phase with the capacitive neutralization, a residual effect remains that must be taken care of by other means if it is objectionable. The local magnetic strays cause disturbance principally by interlinking with the secondary loading coil of the receiving set. Evidence of this was found in the fact that the primary neutralization cannot be appreciably

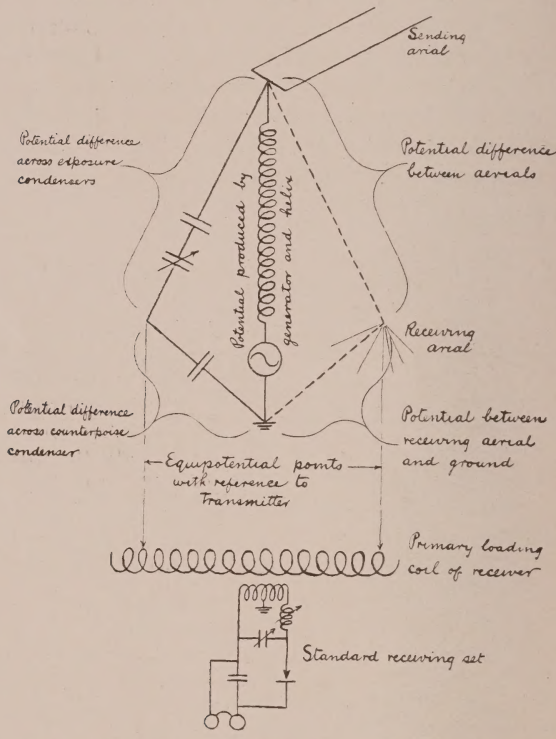
Sending aerial
Potential difference across exposure condensers
Potential difference between aerials
Potential produced by generator and helix
Receiving aerial
Potential difference across counterpoise condenser
Potential between receiving aerial and ground
Equipotential points with reference to Transmitter
Primary loading coil of receiver
Standard receiving set

*Figure 4—System of Duplex Radiotelephony with Capacitive Neutralization

improved upon by the use of a frequency trap. It has furthermore been shown that the local strays can be effectively neutralized by intercepting the strays on a moderate sized wire loop in the neighborhood of the receiving set and impressing the potential so generated on a little coil mounted with an adjustable coupling close to the secondary loading coil of the receiving set.

Figure 3 shows how the final neutralization is accomplished in a more exact way by a phase rotator, P, coupled to the transmitting set.

Figure 5 shows some simple types of antennas that may be proposed for duplex work. The combination of horizontal and umbrella is the arrangement used for the tests described.

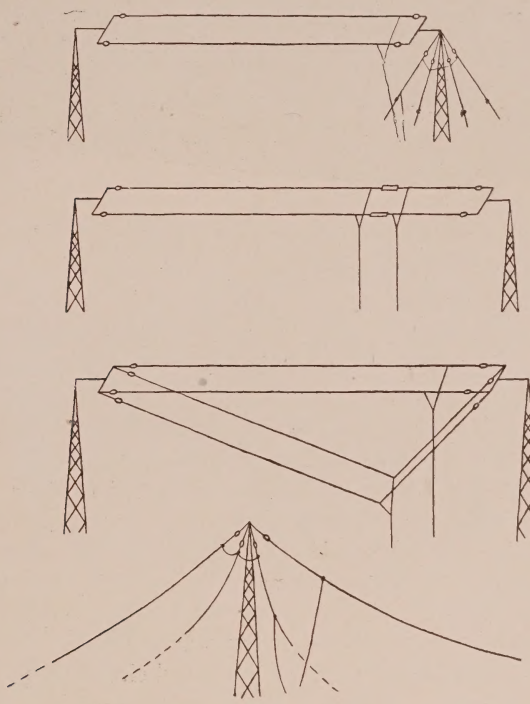

*Figure 5—Antenna Systems for Duplex Radiotelephony

Figure 6 is a photograph of a bridge receiving set, consisting of three units. The bridge coupler shown on the left is the shielded primary tuner shown as T_2 in Figure 3. The receiving set shown at the right of the bridge coupler in Figure 6 is an ordinary type of regenerative receiver. The primary of the receiving set is not tuned, but is adjusted to serve as part of an aperiodic coupling between the tuned primary of the bridge coupler and the tuned secondary of the receiving set. On the

right of the receiving set is the pliotron detector unit. The three units shown in the photograph are separate and may be used in different combinations if desired.

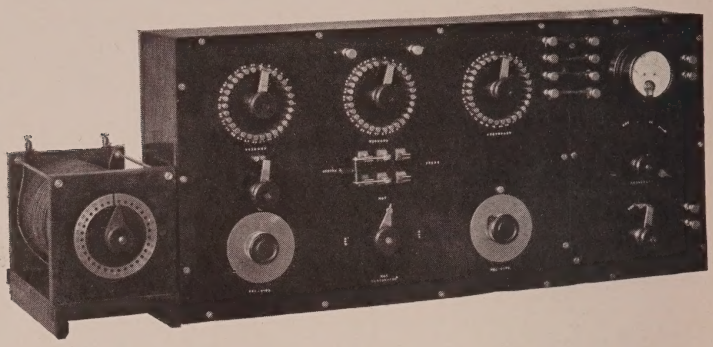

FIGURE 6—Bridge Receiving Set for Duplex Radio Telegraphy

THE BARRAGE RECEIVER

The barrage receiver is fundamentally a uni-directional receiver. The principle of uni-directional reception was first developed by Bellini and Tosi. While the uni-directional Bellini-Tosi receiver has been used as a direction finder, it has, to the knowledge of the author, not been used to any extent for reception of long distance signals. The Bellini-Tosi receiver is based on the principle of receiving the signal thru two antennas of different characteristics and neutralizes the signals received from one direction by a system of balancing. The principle followed by the author in devising the barrage receiver was—

(1) That the antennas or energy collectors should be aperiodic, because the balance of two tuned circuits is fundamentally very delicate and difficult to adjust for a perfect balance.

(2) That the balancing should consist in neutralizing the electromotive forces in the aperiodic antennas before those electromotive forces have had a chance to create oscillating currents. The phase shifting device should therefore be aperiodic.

(3) The two or more antennas should be of the same character; in other words, it is preferable to balance a magnetic exposure against another magnetic exposure rather than against an electrostatic exposure.

The uni-directional Bellini-Tosi receiver works on the principle that the electromagnetic and electrostatic exposures are 90° out of phase. The barrage receiver takes advantage of

the geographic phase displacement in the wave as it travels over the surface of the earth. In the first barrage receivers which have been installed, the antennas consist of two insulated wires laid on the ground a distance of two miles (3.2 km.) in each direction from the receiving station. It was originally intended by the author to mount the wires on poles, but the easier procedure of laying the wires on the ground was adopted at the suggestion of Lieutenant-Commander A. Hoyt Taylor, and the arrangement has proven entirely satisfactory. The barrage receiving set, photographs of which are shown in Figures 7 and 8, consists of a standard receiving set, combined with a phase rotator set. Figure 8 shows the receiving set proper lifted out

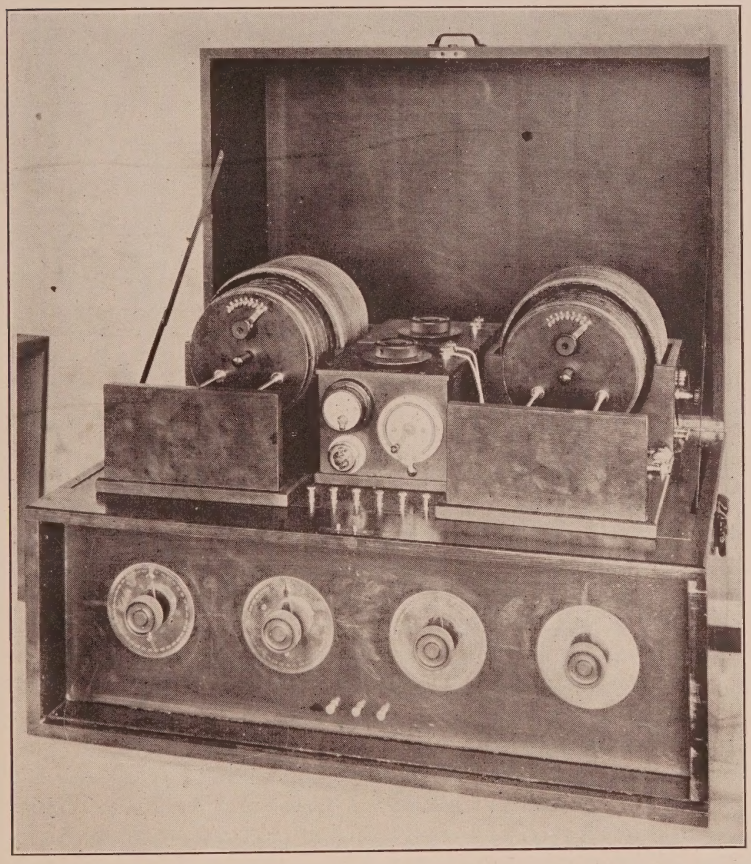

FIGURE 7—Radio Receiving Set with Barrage Section

of the box. This part of the set is arranged so that it can be used as an ordinary receiving set. When used as a barrage receiver, a condenser is used in place of the antenna and the set is coupled to the aperiodic antenna by the phase rotator set.

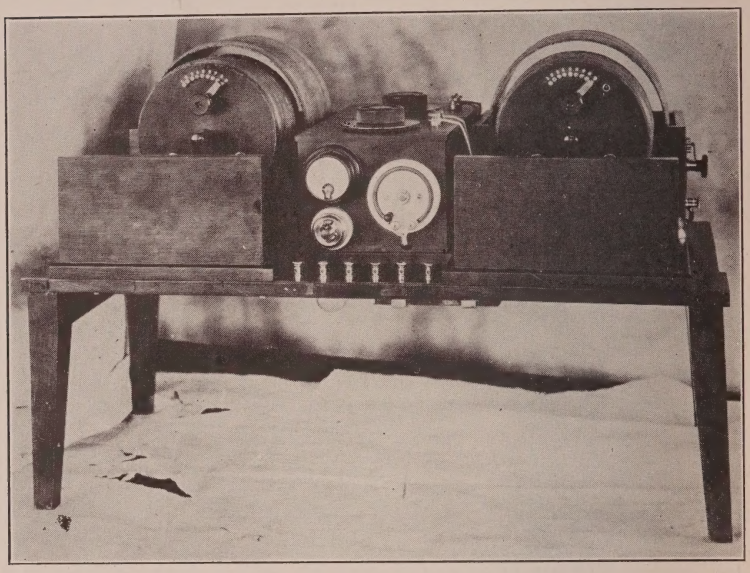

FIGURE 8—Radio Barrage Receiving Set

The diagram of the phase rotator set is shown on Figure 9. Each antenna is connected to ground thru an intensity coupler, the secondaries of the intensity couplers are connected to the primary of the phase rotators. Each phase rotator is built on the principle of a split phase induction motor or induction regulator. A single phase current introduced in the primary is split into a quarter-phase current which produces the equivalent of a rotating magnetic field inductively related to the secondary. By adjusting the position of the secondary coil, the electromotive force induced in it may be made to assume any desired phase relation to the primary voltage. The receiving set proper when used with the barrage receiver has all the normal characteristics of a standard receiving set. A signal originating in any direction whatever may be neutralized by adjustment of the intensity couplers and phase rotators. This adjustment is very easy to

perform, even by an inexperienced operator, and is perfectly stable after it has been made.

An experimental barrage receiving set was operated for several months of the summer and fall of 1918, about three miles from the New Brunswick, New Jersey, radio station. Records were kept on the reception of European stations during the operation of the New Brunswick station. As the New Bruns-

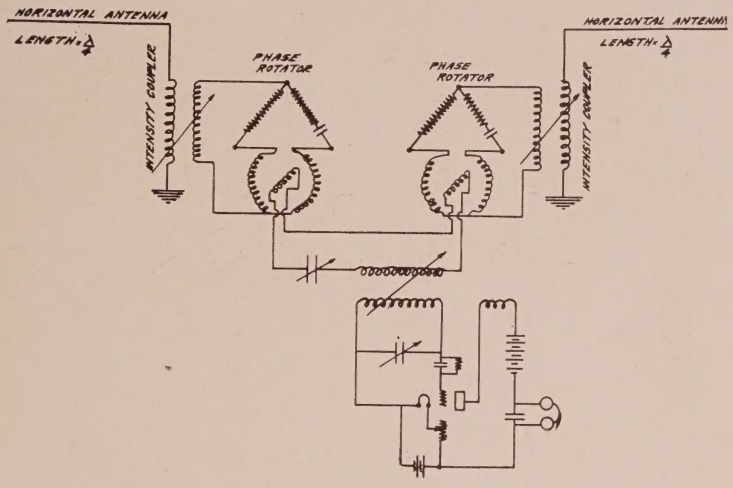

FIGURE 9—Antennas and Receiver of Radio Barrage Set

wick wave is 13,600 meters and the Carnarvon, Wales, wave is 14,200 meters, the reception of Carnarvon was the hardest test to which the set could be put. It was found that in spite of the overwhelming intensity of the New Brunswick signals on an unbalanced receiver, the barrage receiver could be adjusted so that the transmitted wave not only did not interfere with the Carnarvon signals, but the New Brunswick signals could be made entirely inaudible. During these tests it was found that the directive characteristics of the barrage receiver was a material help in reduction of interference by static and strays, as it was found very frequently that solid copy could be obtained by proper directive adjustment, while the signals were practically unreadable with ordinary methods. Statistics of this will be presented in some later paper as the barrage receiver was not originally designed for stray elimination. The improvement of reception of signals by the use of the barrage receiver depends upon the

highly directive qualities of this receiving system. For comparison with other methods of directive reception, a tabulation of directiveness is given. In this comparison the symmetrical elevated antenna which receives equally from all directions is designated at 100 per cent. The percentages of directivity are calculated from the areas of the corresponding horizontal plane intensity diagrams shown in Figure 10. If the directivity represented by the intensity diagrams can be taken as relative measure of the average stray-to-signal ratio, we find that the magnetic loop should have 50 per cent as much strays as the elevated antenna,

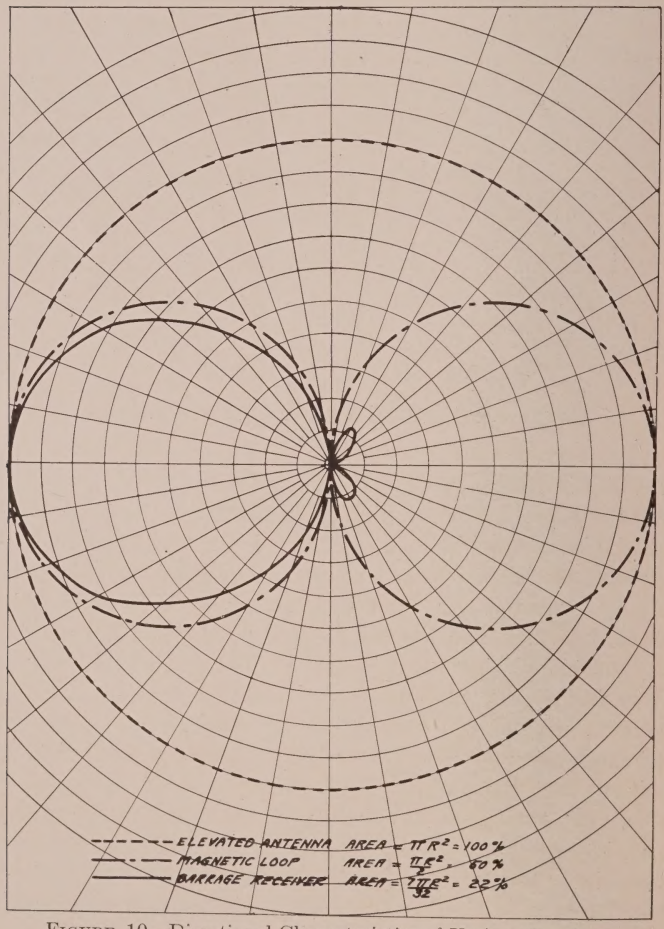

FIGURE 10—Directional Characteristics of Various Receivers

the differential horizontal antenna (Sayville, Long Island), probably about the same as the magnetic loop, and the barrage receiver 22 per cent. Statistics of reception indicate that these figures are reasonably in agreement with facts, when the strays are evenly distributed. When the strays are directive the improvement is much greater.

A rather surprising characteristic was discovered by the use of the barrage receiver. It was expected that this receiver could be used to neutralize signals from all directions except the direction close to the signal to be received. As a matter of fact it was found that interference could be neutralized, originating in the same direction as the signal. This was first discovered in the New Brunswick installation. Signals from San Diego, California, right in line with the transmitting station could be received without great reduction in intensity, while the set was adjusted so as to neutralize the transmitting station. The explanation for this is the fact that in the case of the nearby station, the wave front is curved and the radiation diverging, whereas in the case of the far-away station the radiation is parallel. The receiving antenna covers a space of four miles (6.4 km.), and in this space there is sufficient divergence of the radiation from the nearby station so that an adjustment can be made whereby the diverging and parallel radiation have different effect upon the receiving set. The phenomenon is comparable to the focussing of a field glass on nearby and distant objects. In this case we have a radio field glass of four miles (6.4 km.) in diameter; and, for such dimensions, the focussing effect is sufficient, even at considerable distances, to produce an effective discrimination.

While the barrage receiver was worked out primarily to avoid interference in transoceanic communication, it may be found useful also for the purposes for which the bridge receiver was developed, that is, simultaneous sending and receiving from small shore stations or ship stations. In such cases, it has the advantage over the bridge receiver that it can be used not only to neutralize the transmitting station to which it belongs, but can neutralize interference from any other ship or shore station. By the use of a double set of phase rotators, the barrage receiver may be used to neutralize two stations in different directions simultaneously, and this principle may be carried still further if desired. It is thus hoped that this development will open up new possibilities in dealing with a problem which is perhaps the most important in the immediate future, that is, to meet the

demands on the radio technique for a rapidly increasing number of systems of communication.

January 25, 1919.

SUMMARY: A system of simultaneous reception and transmission for radio telephony is described, together with the reasons for its use. It involves transferring the received speech (from a separate receiving antenna at some distance from the transmitting antenna) to the subscriber's line, and transferring speech originating at the subscriber's station to the radiophone transmitter.

Another type of duplex radio communication is considered, this being based on nearby receiving and transmitting antennas so arranged with their associated apparatus that the receiver and transmitter are in conjugate branches of a Wheatstone bridge. The wiring of the bridge receiver is given and the apparatus shown.

A so-called "barrage receiver" is then described. This is a highly directional combination of aperiodic antennas, with unilateral directional characteristic. When two aperiodic antennas are used, the phase difference of the received currents produced in them depends on the direction of the incoming signals. By phase shifting devices and differential coupling to a common receiver, the signals from any given direction can be balanced out. The wiring and apparatus and its functioning are described.

DISCUSSION

William H. Priess: The ingenious conception of static balance of transmitting and receiving antennas by Mr. Alexanderson, and his disclosure of this invention to the Navy Department in the early period of the War, was responsible for the instigation of a general research at the Washington Navy Yard along the general lines of balancing signal interference. Mr. Israel has covered many of the systems that were tested. I shall attempt to cover some of the general features of the different systems.

At an early stage in the progress of the research it was noted, in some cases, that an absorption of the received signal occurred when the transmitting antenna was connected to the receiving antenna thru the balancing system. An attempt was made to determine the magnitude of this absorption. Reference will be made to the characteristics of five typical systems. (Figure 1 to Figure 5 inclusive.) The method for determining the absorption, due to the balance system, was by measuring the change in audibility of received signal following the change from a simple receiving system to the balance system, in a constant signal sent for this purpose from a distant quenched spark transmitter. The audibility was first checked with the transmitting antenna disconnected. The transmitting antenna was then connected and the best balance obtained. The transmitter was shut down and, with the balance undisturbed, a second audibility reading

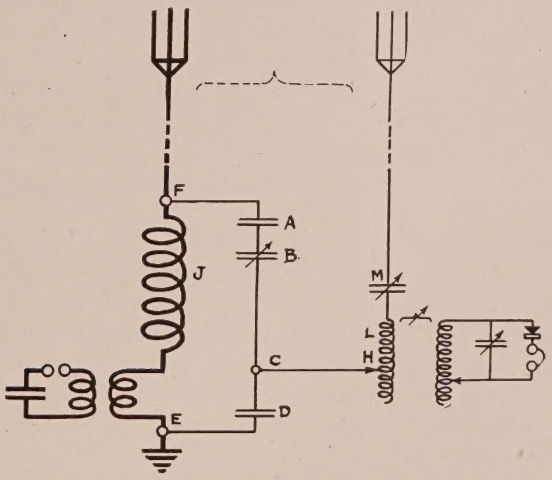

FIGURE 1—Alexanderson Static Balance

was taken. It was found that the systems shown in Figure 1 and Figure 2, as well as a system combining both Figure 1 and Figure 2 (Figure 1, inserting a coil in series with the lead *C H* and coupling it with coil *J*), absorbed about two-thirds of the received signal. Systems 3, 4, and 5, as well as their combinations, showed no appreciable signal absorption, that is to say, showed absorptions less than 10 per cent. It was expected that System 2 and System 3 would suffer equal absorptions. The time al-

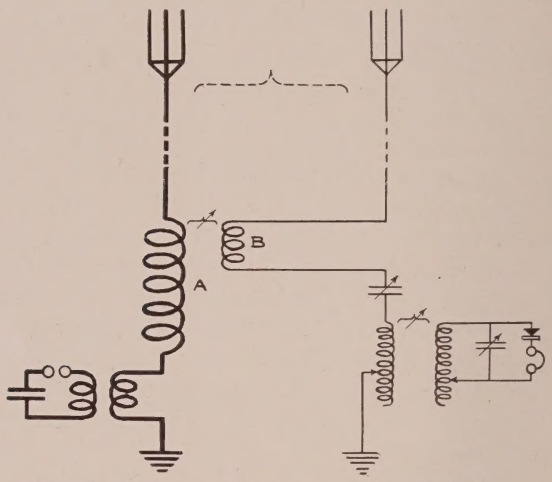

FIGURE 2—New York Navy Yard Magnetic Balance

lotted to the problem was insufficient for thoroly investigating the difference. However, it was found that coil *B*, Figure 3, was opposite in sense to coil *B*, Figure 2, for balance of the two systems. These tests were made with the local transmitter at 1,800 meters and the distant transmitter at 750 meters.

The detuning of the transmitter due to the balance system is an important factor. System 1 caused the greatest detuning and required a process of a series of approximate adjustments between transmitter, receiver, and balancing condensers, that proved very tedious, rendering a wave changer impracticable. Systems 2 and 3 were open to the same objection to a lesser degree. In Systems 4 and 5, this factor did not enter. Combinations of Systems 4 and 5 and uncoupled infinite impedance circuit (inserted for example in lead *AE* of Figure 4), were also free from appreciable reaction on the transmitter.

It was both interesting and annoying to note that minimum residual noise in the telephones and minimum current in the balanced receiving antennas were not in correspondence. With

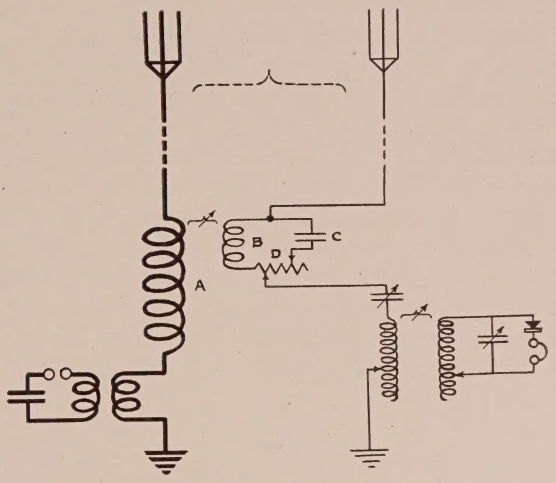

FIGURE 3—Infinite Impedance Circuit

10 amperes in the transmitting antenna at 1,800 meters, and with the receiver at 750 meters; in the first system minimum interference occurred with 160 milli-amperes in the receiving antenna,

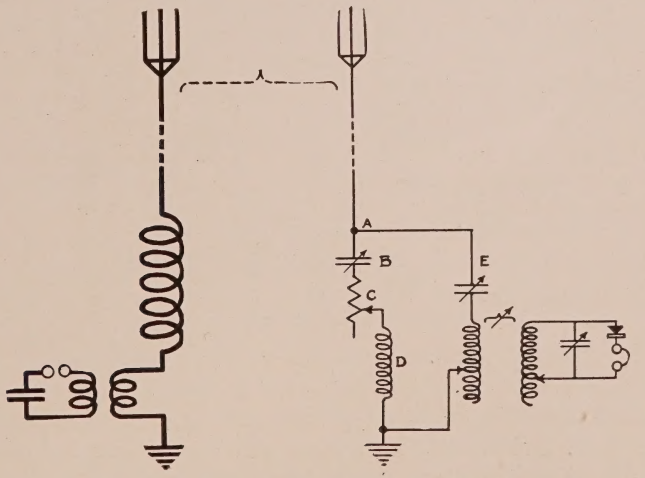

FIGURE 4—Zero Impedance Circuit

altho the receiving antenna could be balanced to 8 milli-amperes. In the second system, minimum interference occurred with 100 milli-amperes in the receiving antenna. In this case, the receiving antenna could be balanced, as the previous one, to 8 milli-amperes. System 5 gave practically a complete balance at the telephones, altho 600 milli-amperes were present in the receiving antenna.

Measurements were made to determine the percentage difference in wave length at which the systems were operable from a practical viewpoint. In the particular case of both the receiver and transmitter in the same room, and both the local and distant transmitters of the quenched spark type, with the local transmitter of the longer wave length; this limit is at about 50 per cent. of the transmitter wave lengths. The detector balance system (Figure 5) proved to be the best combination in this respect. It requires a special receiver primary design to handle the high currents and potentials developed. I made a set of comparative

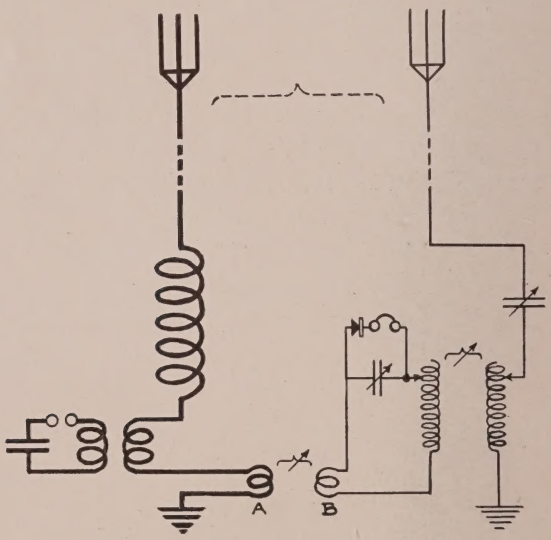

FIGURE 5—Detector Balance Circuit

measurements in an attempt to reach the respective limits of Systems 1 and 5. The antenna systems are shown in Figure 6. The local transmitter was a 5-kilowatt, 500-cycle, quenched

spark set operating at 1,820 meters. The local transmitter wave length was maintained a constant thruout the test. The distant transmitter was likewise a 500-cycle quenched spark set and was variable in both power and wave length. Each set

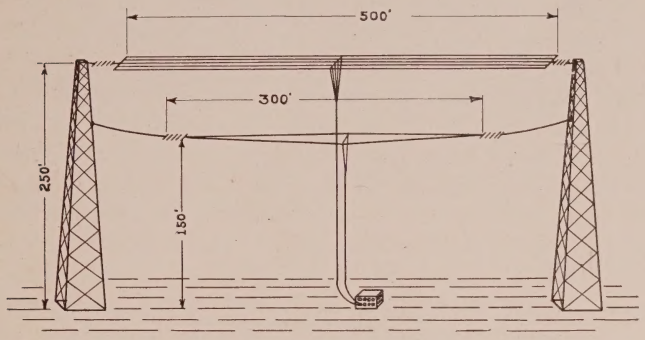

FIGURE 6

of readings was made with the wave length of the distant transmitter constant, varying the powers of both sets to the limits of the systems. One set of readings made with the distant transmitter at 700 meters, from my notes of June 21, 1917, is the following:

	System 1	System 5
Local transmitter antenna current	7.0 amperes	18.5 amperes
Local transmitter transformer input	0.8 KW.	5 KW.
Distant transmitter antenna current	10 amperes	4 amperes
Primary receiver current at balance	150 milli-amperes	0.78 amperes
Primary receiver potential	Approx. 10,000 volts	Approx. 1,000 volts
Residual noise in telephones	Great	Small
Operators at receiver	M. Kenney, Chief Elec. U. S. N.	Wiseman, Elec. 1st Class, U. S. N.
	J. McDonald, Chief Elec. U. S. N.	Wolf, Elec. 1st Class, U. S. N.
Quality of received signal	Barely readable thru interference.	Very good.

In this test, in System 1, the whole primary of the receiver was at from 10,000 volts to 15,000 volts above the ground, rendering receiver adjustment very difficult. This is apparent from a consideration of Figures 1 and 6. The potential of the receiving antenna due to the transmitter may be represented by some point on coil J, Figure 1. Since the coupling between the antennas is high, this point is shifted towards the antenna end of coil J with a consequent raising of the potential of the whole primary of the receiver ($CHLM$) above the ground. In the

particular antenna combination shown in Figure 6, the capacity of the AB condenser combination (Figure 1) was $\frac{1}{3}$ the capacity of condenser D (Figure 1).

The current and potential design of the receiver circuits are obvious from a consideration of Figures 1-5. However, several general features may be mentioned. In both the infinite impedance and zero impedance combinations it was found that the important condition for minimum residual noise in the telephones was to make the decrements of these circuits approximately equal to the decrement of the transmitter. Extremely high capacity and associated low inductance circuits are to be avoided. Extremely high capacities are necessarily only stepwise variable. Therefore, a continuously variable, extremely small inductance would also have to be used. The brush contact resistance in a continuously variable inductance may introduce a very troublesome factor in raising the resulting uncontrollable decrement of the combination above allowable limits. The circuits should be designed so that a small amount of controlling resistance is permissible. It should be noted that in System 4, variations of resistance C between 2 and 100 ohms caused no change in the current in the zero impedance circuit.

The detector balance system requires one variable for control, namely, coupling between transmitting antenna and secondary of the receiver. The coupling between the primary and secondary of the receiver should be pure electromagnetic and fixed at a value that gives maximum audibility with the simple receiver. It is obvious that if this coupling is varied, a variation of the transmitter-detector balance will be required to compensate for the change. An example of satisfactory coupling coils AB, Figure 5, used in the research are:

A-4 turns, 3.5 inches (8.89 cm.) diameter

B-9 turns, 3.5 inches (8.89 cm.)

Coils coaxial and separated approximately 3 inches (7.02 cm.) These coils were adequate for receiving wave lengths up to 1,000 meters when transmitting on 1,820 meters.

The final point I wish to make is the geographical natures of the systems. The receivers of Systems 1, 2, 3, and 5 must be located near the transmitter as they operate on the balance principle. System 4 may be remote as it operates on the filter principle. Zero impedance or infinite impedance circuits, either single or in combination, furnish the most interesting field as their solutions are in the line of general solutions for all cases of simultaneous whether remote or local.

Mr. Alexanderson's second paper on the "Barrage Receiver" is of unusual interest in its vivid depiction of the flexible control of radio frequency phase relations. Looking over some patents of an early date, I found the following combination of tuned magnetic receiving loop with central point grounded. The interesting portion is circuit C for adjusting the phase of the electrostatic component of the wave impressed on the grounded antenna AD, so that both the electrostatic component of the wave impressed on it and the electromagnetic component impressed on the magnetic loop A, are added together in the desired common receiving circuit F. This work was done in 1907 and is the earliest public mention I can find on deliberate phase adjustment in radio frequency circuits. It has apparently not received the general attention of radio engineers for a number of years. This matter of phase adjustment is interesting in view of the papers delivered by Mr. Weagant and Mr. Alexanderson and is merely offered as a suggestion.

John V. L. Hogan: Whose patent was that, do you remember?

William H. Priess; Mr. Pickard's patent of 1908 (876,996).

Another interesting point in connection with the balancing of interference may be made, namely, the balancing of static interference. The ratio of signal to static intensity on a magnetic loop differs from the ratio of signal to static on a straight grounded antenna. The circuit previously shown in Figure 7 provides a system of static balance by amplitude. After adjusting in circuit C the phase of the electrostatic component of the wave received on the grounded antenna DA, so that it corresponds with the phase in circuit B of electromagnetic component of the wave received on the loop A, the two components are added negatively in the receiver circuit F. By varying the coupling between circuits C and F with respect to the coupling between circuits B and F, to the point where the emf. due to static induced across circuit F by circuit C is equal and opposite to the emf. due to static induced across circuit F by circuit B, the total emf, due to static in the detector circuit F becomes zero. However, since the ratio of signal to static is different on the loop from what it is on the grounded antenna, a residual emf. due solely to the signal wave remains in circuit F. The pure signal may be amplified if required without reaction on the system. This is the system of static elimination by

amplitude balance. The apparatus, including antennas, is local and can be used on a ship. Only one adjustment is necessary and that is the relative couplings of receiver and transfer circuits, *F*, *B*, and *C*.

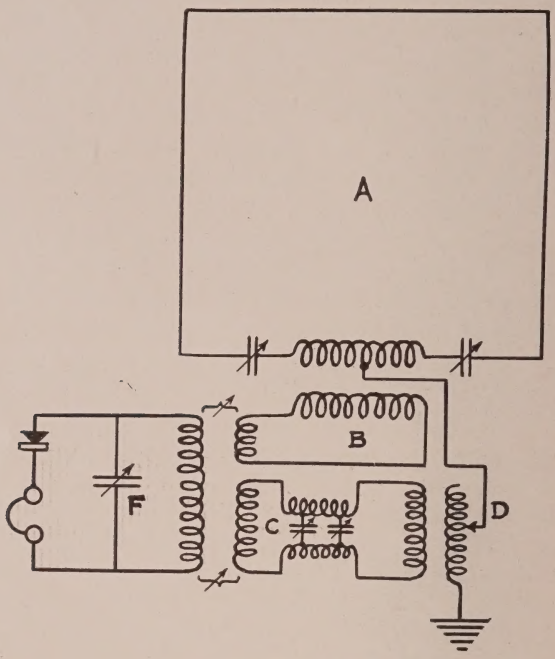

FIGURE 7

Lloyd Espenschied: I should like to ask Mr. Alexanderson if he has available any engineering data on the balance between two closely adjacent antennas which it is possible to obtain experimentally and also that which it is practicable to maintain in service. It should be observed that the two general principles involved in Mr. Alexanderson's work whereby it is possible to exclude the interference from the home sending station are those of selectivity involving a difference in frequency between the sending and receiving transmissions, and of directivity permitting of balance. It would be helpful were it possible for Mr. Alexanderson to evaluate the individual effects of these two methods in separating the undesired from the desired transmission; that is, to what extent and under what conditions may

balance be relied upon and to what extent must balance be supplemented by selectivity Quantitative data of this kind must be had, of course, before duplex radio can be adequately engineered and maintained in service.

Two types of balance are illustrated by Mr. Alexanderson, one in which the balance is effected between the real antenna and a dummy or artificial antenna, and the other in which balance is as between two real antennas. We should expect the maintenance of a balance by means of an artificial antenna to be attended by some difficulty because of changes in the antenna constants caused by varying weather conditions. In this respect, the constancy of balance should be better for the system employing in effect two conjugate real antennas, considering the loop antenna as a form of the latter type.

(After Mr. Alexanderson's answer): It appears then that the balance as measured by current ratio is of the order of a million. It is of interest to note that even allowing for the fact that this result is obtained by refined experimentation, it seems to be much better than the balance which obtains in ordinary duplex operation over land lines. We should, of course, expect to be able to obtain a higher degree of balance in employing a localized structure such as an antenna than is possible under the conditions of wire transmission where the line extends over considerable territory.

Lieutenant M. W. Arps: 1. I notice in the descriptions of experiments made, that Mr. Alexanderson states that the antennas are two miles (3.2 km.) long. Of course, that is impractical on ship work. Antennas 250 feet (80 m.) in each direction are what we have on board ship and what we do work on.

2. Regarding the latter type of barrage receiver, with the experience that the ordinary operator has, it is hard to have him tune two circuits. I should like to know whether the barrage type of receiver is developed to such a point where you could have it on board ship and have the ordinary operator obtain good results.

C. L. Farrand: I am exceedingly interested in the paper Mr. Alexanderson has delivered this evening. The problem of simultaneous transmission and reception and the problem of the barrage receiver are very similar. The latter is better known to me than the first. The general problem involved is producing a receiving system that is responsive to the desired signal and unresponsive to the undesired signal dy differentiating between

peculiar characteristics of each. The desired signal is in all cases that of the distant transmitter. The undesired signal may be from the associated transmitter, which may be very immediate, or at a reasonable distance, an interfering station, static or combination of these three.

Mr. Alexanderson has shown us how successfully a system of this nature can be operated, even when the interfering station was on exactly the same wave length and in the line of direction of the distant station. In the previous discussion, there are mentioned early trials endeavoring simultaneously to transmit and receive, and which have been accompanied by success of greater or less degree. The earliest date of their experiments, I believe, was in 1914. A very early work along these lines was done by Sir Oliver Lodge who, in 1898, took out patents in this country as indicated in the following sketch (see Figure 1), wherein he shows two rectilinear antennas tuned by means of condensers and inductances. Unfortunately, altho he describes the use of the

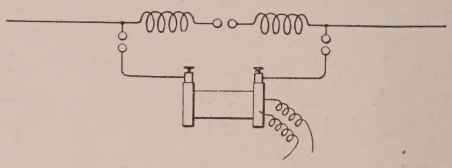

FIGURE 1

system for reception, he does not show the mode of connection, and leaves it to one's imagination that the spark gaps will be replaced by coherers. So it may be considered as stretching the point to consider that his disclosure was suitable for interference prevention. However, an American inventor, very well known to the Institute, Mr. John Stone Stone, in 1901 indicated that he had a very clear conception of the problem by the disclosure in his American patent of a system for simultaneous transmission and reception, somewhat as indicated in the sketch (see Figure 2). Three antennas are shown erected in the direction of propagation of the signal and spaced preferably, the specification says, a total half wave length. The central antenna is used for transmitting, and is spaced a quarter wave length from the adjacent receiving antenna. The receiving antenna is coupled to a common receiver, and in combination is responsive to the distant transmitter and unresponsive to the associated transmitter.

Balancing antennas have been used extensively for different purposes. The Marconi trans-Atlantic stations have used balancing antenna for simultaneous transmission and reception, or "duplexing," as it is termed. The system consisted of a long horizontal antenna, in the direction of reception, usually a single wire several hundred feet (about 100 m.) high and of relatively greater length, for the main receiving antenna. The balancing

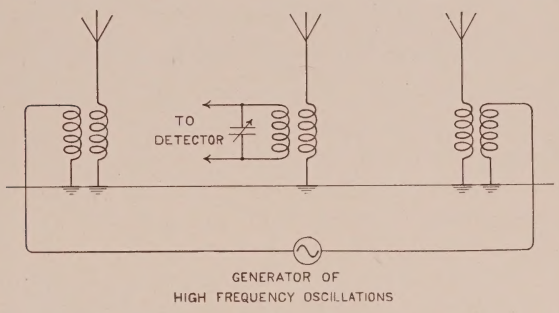

FIGURE 2

antenna was placed at right angles to the receiving antenna, and principally receptive from the associated transmitter, and usually consisted of a single wire less than a hundred feet (30 m.) high and of length equal to the receiving antenna, approximately. The object was to balance out the signal of the associated transmitter. It was considered that the low balancing antenna would receive the signal of that transmitter in greater ratio to the signal of the distant transmitter, than the main receiving antenna. It is rather difficult now to realize that these efforts along the line of duplexing did not accomplish static reduction, but probably it can be accounted for by static reduction not being the object of the experiments, the dissimilarity of the antenna, the relatively poor phase relations existing due to the use of long waves, and the small separation of the electrical centers of the antenna which with the crystal detectors then used did not permit of proper phasing, as sufficient energy could not then be extracted.

Two general methods of attack have been considered in the discussion for reducing interference from signal and static, first is one which Mr. Priess has mentioned, and to which I have devoted considerable attention, dependent upon the inequality of the ratios of the amplitudes of static to signal in two receiving

systems; the second is dependent upon the inequality of phase relation of static to signal in two receiving systems. If two receiving systems could be constructed which would receive static and signal in unequal ratio, a very positive method of eliminating static would result. It seems that the success of the attempts to reduce interference has been due principally to the unequal phase relations, rather than to the inequality of amplitude ratios.

RADIO TELEGRAPHY IN COMPETITION WITH WIRE TELEGRAPHY IN OVERLAND WORK*

By

Robert Boyd Black

(Federal Telegraph Company San Francisco California)

Since the first days of radio telegraphy, numerous attempts have been made by the radio companies to handle commercial business in competition with the land telegraph and cable companies. When there has been any effort at active competition on the part of the wire companies, these attempts have invariably failed. In a few isolated places where wire service was impracticable, radio stations have been in operation for several years and have given a suitable return on the original investment. But it is safe to say that until the introduction of the present efficient type of radio duplexes, competition from the radio companies was not looked upon seriously by the wire companies.

Perhaps if the failure of the radio companies were investigated it would be found to be chiefly a matter of lack of business planning. Most of the half-hearted attempts at competition that have heretofore been made by the radio companies in this field have been carried out with an absolute disregard of expense of operation. Competition to be successful must be founded on a sound economic basis, and with due regard to the operating expenses in comparison with those of other companies in the same field.

Facilities for furnishing reliable and efficient service at a reasonable cost have been lacking in the radio field in the past. Radio stations, for the most part, have been located in inaccessible parts of the cities they were supposed to serve. In some cases, they have been several miles out of the city, which necessitated the relaying of messages over a telegraph or telephone wire, with consequent loss of time, liability to error, and duplication of personnel.

On the radio circuit, the receiver was unable to "break" (i. e., interrupt) the sender, and numerous corrections were

* Received by the Editor, May 1, 1917. This paper was written prior to April 1, 1917.

necessary, caused by unreliable apparatus, atmospheric strays, interference, and other causes. When the sender had finished, it was necessary some times for the receiver practically to skeletonize some messages back to the sending station, in order to secure the scattered missing words from his copy. This resulted in a very ragged looking copy unfit to be delivered directly to a customer, and generally necessitated recopying—a very dangerous practice from the standpoint of accuracy. Moreover, because of the fact that the radio operator has had no means of knowing when he was being called by another station except when wearing the telephones, he has been under the necessity of keeping the head set on constantly or of making "dates" or appointments with the distant stations. Neither of these methods has proven entirely satisfactory from the standpoint of efficiency.

The constant wearing of heavy, tightly fitting head telephone receivers is distinctly detrimental to the health and efficiency of the operator. Besides the danger of ear infection, there is also the liability to other head troubles arising from the constant pressure and strain involved in this method of reception. Furthermore, an operator wearing head receivers is limited by the length of his telephone cords in performing the other necessary duties of a telegraph office. These duties, in a small office, would include waiting on customers, supervising delivery of messages, and attending to the telephone.

Another disadvantage to the radio companies has been the lack of a sufficient number of feeder stations to supply the main trunk circuits. The leading wire companies have offices in practically every town and village, and the greater portion of the traffic which is handled on the trunk lines between the larger cities is relayed from the smaller towns. The radio companies have usually contented themselves with the establishment of stations in some of the larger cities, handling only the business originating at those points. It is manifestly impossible for one company to secure all the business originating in any one city where there are other companies in competition, and it naturally follows that a network of stations should be operated in order to keep the main trunks working to their full capacity.

Lack of efficient organization and thoro training of employees has, in some cases, proven a great detriment to the development of radio in this field. Because of the use of different telegraph codes by the wire companies and the radio companies in the United States, a number of expert Morse telegraphers, who might

otherwise have been available for radio work, have remained with the wire companies. It is hard to train men in a new code in a limited time, and those who have developed into good telegraphers were usually poor electricians, and vice versa. There has been a dearth of fast Continental code circuits in the United States for training operators in high speed work.

All these factors have combined to work against the success of radio in the competitive field; and, coupled with the high cost of operation under these conditions, has invariably resulted in the elimination of the radio companies.

With the recent introduction of greatly improved apparatus for both sending and receiving, it would seem that radio is in a fair way to compete with wire service in practically every department of the work, including the handling of fast press service. The art has lately advanced to a stage of fine tuning, minimum interference, and good results with an amount of power that would not have been thought possible a few years ago.

Multiple radio circuits have been thoroly tried out for a year or more in regular commercial work, and have been found to be quite as efficient and reliable as the wire circuits. It has been demonstrated that messages can be copied directly on the typewriter at a station located in the heart of the city, without undue interference from nearby power and radio stations. The increase in traffic capacity of the circuits and the consequent lower cost of operation has made the future of radio look very promising.

Experiments which are now being conducted, with a view to the elimination of head receivers and the substitution of audible devices for receiving, have shown very good results where the received signals are of reasonable audibility. The great advantage of such a receiving device would, of course, be for calling purposes, but its use in regular work would undoubtedly prove advantageous. With a reliable device of this kind, an operator would be available, when not actually receiving on one circuit, to listen in, or to receive on another circuit, and at all times be able to hear any other station which might call. Following the system of the wire companies in this respect, one operator could cover several circuits, where the amount of business on one circuit would not be sufficient to keep him busy. It would not be necessary to make "dates" with any station. Every station would secure practically uninterrupted service.

From the results actually accomplished to date in radio work and in view of the improvements which are contemplated, a

fairly accurate estimate can be made as to the general organization and conducting of an ideal system of competitive radio telegraph service. Some of the most pressing needs of such a system will be outlined in this paper.

Main Trunks

Between the larger cities there should be established a sufficient number of radio duplexes to take care of all business offered, and to handle it with accuracy and despatch. For the purpose of this paper, these stations will be designated as "relay stations."

The distance by which these stations may be separated is of course dependent upon factors which would be different in different localities. Suffice it to say, that they must be able to carry on fast, reliable communication under all conditions.

"Way" Circuits

From each relay station there should be operated several local circuits, corresponding to the "way" wires of the wire companies. These way stations should be grouped together so that a certain number of them, depending on the business they handled, would send to the relay station on the same wave length. They should each be able to hear every other station in their group in order to prevent interference by simultaneous sending on the same wave.

Relay Station

At the relay stations all business would be handled at the receiving office, which should be located as near as possible to the telegraph center of the city which it served. This would be very necessary in order that the radio company might secure its just share of the available business, and in order to facilitate deliveries from the central location.

The location should be chosen with a view to the erection of an antenna or antennas between two or more comparatively tall office buildings. The best results would probably be obtained by having the space between these buildings and around them comparatively free from obstruction, but this has not been found absolutely necessary in practice. A ground can be made to any convenient water pipe. Very good results in receiving have been obtained from this type of antenna and the expense of erection is slight.

The business office, where messages are accepted for transmission, should have a good ground floor frontage. The operating room should be located in close proximity to the business office, and communication between them should be maintained by a pneumatic tube or similar system.

The operating tables and operators should be grouped together as closely as possible, to facilitate the handling of relay messages. On all duplexes the sender should sit directly beside, or opposite the receiver, and should be provided with a single head telephone or other means of receiving his own "breaks" from the distant station. The sender should also be provided with some device to show that his signals are leaving the sending station properly. There are several ways of arranging a device of this kind, the simplest probably being the introduction of a separate receiving set tuned to the sending wave length. This provides the best possible check on the signals from the transmitting station and the action of the repeating key, and permits instant correction of faults in the transmitter, thereby minimizing the necessity for breaking.

All receiving instruments should be easily adjustable from a sitting position. All variable condensers in the sets should be of small capacity, with long indicators moving in a large arc, so that a maximum movement would be recorded for a moderate change in wave length, and the tuning thereby made finer. The points of maximum audibility should be plainly marked.

All control circuits leading to the transmitting station or stations should be available from each position, preferably by the use of telegraph jack and plug switches.

An easy-running, visible-writing typewriter should be provided for receiving, preferably with all capital letters and without a shift-key. Particular attention should be paid to all time-saving features. Devices for increasing the audibility of received signals should be installed as soon as they are found to be practicable for commercial work.

Transmitting Stations

Transmitting stations should be located a sufficient distance from the receiving office to prevent undue interference. In practice two or three miles (3 to 5 km.) has been found to be sufficient. Normally no receiving should be done at the transmitting station, the whole power output and the regulation of wave lengths being under control of the receiving operator. A

wave changing switch with a sufficient number of points for all necessary changes of wave length should be provided, and these wave lengths should correspond exactly with those of any other transmitting stations in the same city. In case of the failure of one station, another could then be immediately put on the desired wave length and transmission resumed without delay.

Some signal checking device should be provided with the regular equipment at all transmitting stations, which would allow the operator in charge greater freedom for making repairs and attending to other necessary duties about the station. A sparking wavemeter, coupled to the transmitter helix, and consisting of an inductance and a variable condenser tuned to the sending wave length, gives very good results for this purpose. Sparking takes place between the condenser plates, furnishing signals which are audible as long as the set is operating perfectly. The sound may be re-enforced by placing the condenser in a resonator.

In all cases where the power is used intermittently, a considerable saving could be effected by providing distant control of the power source.

Way Stations

Way stations, for the most part, should be established in the smaller towns in the vicinity of the relay stations. Normally, they would transmit their business to the nearest relay station, excepting that which was destined to stations in their own group.

In practice it has been found that altho it is possible for the way station to send its messages directly to its destination, time may be saved by relaying it; for by so routing it work over trunk circuits goes on uninterruptedly.

The duplexing of such stations would hardly pay at present, involving, as it does, the erection of one station for sending and one for receiving, with consequent additional cost for maintenance and operation. These circuits would, in effect, be in multiple at the relay station; and the way station (where one man would act as operator and manager) would be able to "break" at any time to answer the telephone, wait on the counter or attend to other duties. With late types of reliable receiving instruments there should be very little necessity for "breaking" at the relay station. At these the operator would have no outside duties to perform.

In a way station, the complete sending and receiving equipment should be located in a ground floor office, near the center

of the business district, in at least as good a location as that of the competing telegraph companies. In all cases the necessary motor generator set should be started and stopped from the operating table by a remote control. A wave changer should be installed within easy reaching distance, as should the rest of the set. A fast repeating (relay) key should be provided, operated by a small Morse key. A sparking wavemeter should be provided to show that the station was radiating properly.

In the receiving set several pairs of condensers and inductances should be provided, each pair tuned to a certain wave length, and any set instantly available by throwing a single switch. If it were desired to receive on any other than the regular wave length, it would only be necessary to throw one switch, which should be wired up to include the necessary inductance and capacity for the desired wave length. This would save the valuable time lost in tuning for the different wave.

The change from sending to receiving positions should all be done in one switch. The other arrangements should be practically the same as for a relay station.

Operation

In the operation of this system, the way station, before proceeding to call the relay station, would listen in on the regular wave length which had been allotted to its group. If that circuit were busy, the operator would listen on each of the other wave lengths until he found one which was not being used. He would then proceed to call the relay station, which would be provided with a receiving set attuned to that wave length. Upon receiving a reply he would proceed to send his business upon the idle wave length or upon any other which the relay station might designate. With two or three wave lengths allotted to each way station, and these tuned in and covered at the relay station, there should be very little delay on account of the circuits being in use by other stations. These circuits might be designated as *"A," "B," "C,"* etc., to facilitate quick change from one to another.

The relay station normally would call a way station on one particular wave length and then arrange for transmission on another if the regular wave length were busy.

For intercommunication between two way stations, the call would be made on the regular wave length, and transmission effected on one of the auxiliary wave lengths in order to keep the regular wave length clear for calling purposes.

Operating Details

In the handling of this class of business the methods of the American telegraph companies should be followed as closely as possible consistent with proper observance of the rules governing radio communication. The results arrived at by wire companies in the way of improving the working capacity of a circuit are based upon years of experience and probably represent the highest efficiency obtainable in this regard. It has been proven in actual work that the elimination of unnecessary prefixes and other superfluous characters has been a big factor in increasing the capacity of telegraph circuits.

Automatic, high speed work in radio telegraphy at the present time is dependent upon unusually good atmospheric conditions. While some very good results have been obtained in this line at times, the system on the whole is costly and occasions delays which show up badly in comparison with the fast service of the wire companies. A burst of strays lasting only a fraction of a second is sufficient to obliterate a whole word or more of the high speed signals; whereas an experienced operator, copying at the regular rate of speed, would probably be able to fill in the one or two missing letters which a discharge of the same duration of time would cover. Even among the wire companies, the manual system is still recognized as the more reliable for all around work.

The capacity of the circuit, then, depends to a great extent on the skill of the operators employed. There is room for considerable improvement in this portion of radio work in order to equal the work done by the fast wire operators.

Operators

While ability for fast sending in an operator is desirable, it must be combined with other qualities. Good judgment, cool-headedness and ability to read poor copy are just as necessary qualifications in sending as high speed. Generally speaking, a medium-speed, methodical sender, watching his copy closely, eliminating all unnecessary characters, calling attention to misspelled words, avoiding "combinations," and taking especial care in the transmission of code or unusual words, will make better time than the fast, erratic sender. Automatic transmitters, sending purely mechanical signals, have not proven entirely satisfactory for manual reception on account of the sameness of speed which does not allow for the unusual words.

However, the proportion of rapid hand senders among telegraphers is very small, and a hand sender may find his efficiency impaired at any time by operator's paralysis. An instrument called a "sending machine" is being widely used by telegraphers, both wire and radio at the present time. This is an ingenious instrument which works with a side motion, the lever on one side making contact for the dashes, and on the other side starting a mechanical vibrator which makes dots as long as the key is held over. The characters are formed by combining the action of the two. It can readily be seen that there is a great saving in labor when using such a device, and its use practically eliminates paralysis. It is operated with one hand, leaving the other free for marking off and sorting messages. Properly adjusted, a sending machine permits of faster sending and better spacing, in the hands of the average operator, and it will carry thru on any circuit where fast hand sending will carry.

"Combination" sending is a very common fault among telegraphers and one that should be assiduously guarded against. This is improper timing of the dots, dashes, and spacing. This spoils the whole time rhythm, and the receiving operator has the same difficulty in reading the signals as is usually experienced in listening to a stuttering person over a telephone line. Usually the sender is unaware of this fault and imagines he is sending perfect signals. Probably the best method of showing an operator his failings in this respect is to take phonographic records of his sending and compare them with signals which are correctly timed.

Among the commercial operators of the United States, a knowledge of the Phillips Code of abbreviations is coming to be generally recognized as part of an operator's education. This is a system of abbreviations embracing a large proportion of the most frequently used words of the English language, with a complete system of punctuations. It is based on a very comprehensive plan and follows set rules for terminations. The abbreviations are nearly all suggestive of the word which they represent, and are therefore not difficult to memorize.

In practice, the sender simply sends the correct abbreviation for a word, and the receiver spells it out in full and writes it down. Using a typewriter, this is comparatively easy, as the speed of the average typewriter operator is about double that of the fastest sender. This code is used by all American press and brokers' telegraphers, and enables them almost to double their speed. It is also used considerably on the fast commercial wires, and at all times when press is being handled. Knowledge

of it is always a help to an operator, if only for the accuracy it gives in conversation in connection with the handling of business. It is obvious that if abbreviations are to be used, a regular system should be followed.

The International List of Radio Abbreviations, while forming a handy medium for carrying on a conversation between operators using different languages, is not sufficiently expressive to cover all conditions encountered in telegraph work. Moreover, it is an arbitrary code, not easy to memorize. In the Phillips Code, there are no two abbreviations alike, and if both operators have a good understanding of the code, there is very little liability to error.

A radio duplex, like a wire duplex, is as good as two separate circuits, as long as the number of "breaks" is reduced to a minimum. Therefore both sender and receiver should endeavor to avoid breaks as much as possible. This can only be done by complete co-operation and first class work on the part of each operator. One inefficient man on a duplex can practically nullify the work of the other three.

To the training in this work, and to the general training in concentration, discrimination, and mechanical skill, which only years of experience can give, is due mainly the success in fast radio work of the ex-wire operators who have mastered the Continental code and the necessary technical knowledge. It is admitted among wire telegraphers that it takes on an average of two years or more of all-around experience on the fastest circuits to produce a really first class operator. Even then there are failures, as in every line of endeavor. The equivalent experience on fast radio circuits should give just as good results.

It is obvious that a radio operator must have a good technical knowledge of his apparatus to get the best results. While this knowledge might be subordinated slightly to telegraphic ability in a large office where other expert technical men were available, the knowledge would at all times prove a big asset.

With such an equipment and organization it would seem that a radio company would be in a position to compete successfully with the wire companies in every line of the work. The cost of operation for results achieved should run as low as or lower than that of the wire companies, with their heavy upkeep and right of way costs. The facilities of the radio would, in some ways, be superior to the wire telegraph; and the occasional severe atmospheric difficulties of the radio would be counter-

balanced by the occasional total prostration of the wire telegraph during floods, sleet storms, and the like. In addition, districts could be served where wire service is impracticable because of the physical difficulties which prevent proper maintenance of telegraph lines.

A chain of stations of this type, backed by an efficient organization of employes, would be a valuable asset to the nation and to the districts it served in the event of wire prostration, or national disaster. On this account, it would seem that it would be sound policy for the National Government to encourage and facilitate in every way the extension and operation of such a system.

Probably the nearest approach to the ideal conditions outlined above is furnished by the chain of stations operated by the Federal Telegraph Company on the Pacific Coast. This includes the Los Angeles-San Francisco duplex, and the San Francisco-Portland duplex, and one way "break" systems between Los Angeles and San Diego; Los Angeles and Phoenix, Arizona; and San Francisco and Honolulu.*

The Los Angeles-San Francisco duplex, having been in operation for a period of nearly two years, is probably the best known, and will be described here.

Los Angeles Office

The equipment at the down-town receiving office at Los Angeles consists of two of the latest type sustained wave receiving sets, one normally tuned to receive San Francisco on a wave length of 3,500 meters, and the other normally tuned to receive San Diego and Phoenix on 2,750 meters. The San Diego-Phoenix set can instantly be put in service for receiving damped waves on 600 meters by throwing a single switch.

The antenna for receiving San Francisco is composed of three wires, each 320 feet (100 m.) long, suspended between two office buildings at an average height of 175 feet (53 m.). The San Diego-Phoenix antenna is composed of a single wire, running almost parallel to the San Francisco antenna, and of slightly greater length. No towers are used to suspend these antennas. They are simply swung between the two buildings at the level

* (The distance from Los Angeles to San Francisco is 390 miles, or 625 km.; from San Francisco to Portland, 550 miles, or 880 km.; from Los Angeles to San Diego, 94 miles, or 150 km.; from Los Angeles to Phoenix, 480 miles, or 770 km., and from San Francisco to Honolulu, 2,080 miles, or 3,340 km.—Editor.)

of the roof. Either of these antennas can be used separately for receiving multiplex, making the use of four or more receiving sets practicable.

The operating room is on an open balcony, running across the rear of the main receiving office, which occupies a store front in the center of the city. It is subject to the ordinary noises of the street, but this causes no interference with the received signals, which are ordinarily strong and clear enough to be read under all conditions.

The operating table runs across the front of the balcony and is 12 feet (3.1 m.) long, wings on each end supporting the receiving sets. Pockets are provided at each end of the table for typewriters. Two visible-writing typewriters are used for receiving, and are so located that all tuning can be done while sitting in front of them. The sending operators sit directly beside the receiving operators. Keys operating the control circuits which run to the two transmitting-stations are available from all sending and receiving positions. Telegraph sounders and resonators are provided for the sending operators. A single telephone receiver, on an extension arm, and in series with the receiving phones of the San Francisco board, is provided for the sending operator on that circuit so that he may listen to San Francisco's "breaks."

All induction from telegraph control circuits has been eliminated by the placing of condensers of one microfarad capacity across the line, and the induction from the automatic telephone call system on the main floor has been nullified by the placing of resistance-coils in the telephone ground lead.

All messages, as they are received from the distant stations, are copied directly, in duplicate, on the typewriter, and dropped into a chute (conveniently located beside the receiving operator), which deposits them on the delivery desk on the main floor. Outgoing messages are delivered on the operating table on the balcony, by a device similar to the trolley systems used in department stores. In the handling of relay messages, it is simply a matter of one operator handing them to another.

Two transmitting stations are controlled from this office and are practically duplicates of each other, in so far as power and equipment are concerned, and are three and five miles (5 and 8 km.) from the downtown receiving office. Each transmitting station is equipped with a 12 kilowatt Poulsen arc converter, altho normally less than half of this amount of power is used. Both are arranged for transmitting upon several wave lengths,

the corresponding waves at the two stations being of exactly the same length, so that in case of the failure of one the other may be immediately put on the wave length being used, and transmission resumed without delay. This permits of one station being operated singly on holidays, etc., when there is not sufficient business to warrant keeping two stations in operation.

Normally one station is used for transmitting to San Francisco on a wave length of 3,250 meters, while the other, on a wave length of 3,750 meters, is used for transmitting to San Diego, Phoenix, and the steamships equipped with Federal apparatus, on the Pacific (which constitute a fair sized fleet). Other wave lengths are available for a second sending circuit to San Francisco when business warrants. All the company's sending stations are equipped for sending and receiving on the sustained waves of the Poulsen system. In sending on 600 meters, a "chopper" is used in series with the antenna. This furnishes a very pure musical note, at a frequency of about 500 cycles. The damped wave receivers can be instantly cut in for short wave work. Each station is in charge of a first-grade commercial radio operator. These operators are available for duty at the receiving offices when required, and the operators at the receiving offices are available for duty as arc operators at the transmitting stations. Considerable flexibility in working staff is obtained thru this arrangement.

San Diego and Phoenix normally transmit to Los Angeles on the same wave length, so that no tuning is required to hear either of these stations at any time. In addition, these stations have an auxiliary wave length exactly corresponding to that used by San Francisco, so that they can call Los Angeles on the San Francisco receiving set, or they can use that as a regular wave length when only one man is on duty at the Los Angeles office. During the busy part of the day three, and sometimes four, men are on duty at the Los Angeles office.

San Francisco Office

The receiving office at San Francisco is located on the eighth floor of a twenty-story building, and is provided with two receiving antennas of the same type as those at Los Angeles. One of these antennas is used for receiving Honolulu and the ships and the other is used for receiving Los Angeles and Portland simultaneously, providing quadruplex receiving. Two transmitting stations are controlled from this office one of these being a duplicate of the two Los Angeles stations; and the other at

South San Francisco, has two transmitters and two antennas, providing triplex sending.

Honolulu, as well as Los Angeles and Portland, is copied directly on a typewriter at the San Francisco receiving office and the copies as they are received are dispatched to the delivery department on the first floor thru a pneumatic tube.

At the San Francisco receiving office five or six men are on duty at all times during the day, working side by side, and handling heavy traffic, without interference. Moreover, the San Francisco office is in the center of the interference zone of the Pacific Coast, there being five high power stations in the immediate vicinity.

The work with Honolulu has been carried on for about five years and has been very satisfactory. A regular commercial service has been maintained and most of the news service carried by the Honolulu papers has been handled by the Federal Telegraph Company. The Honolulu end of this circuit will be duplexed in the near future to take care of increasing business.

A fast duplex service is maintained with Portland, the second antenna at the South San Francisco transmitting station being used for this purpose. It was found necessary at this station to use two antennas very nearly at right angles to each other, and two arcs for transmitting on two wave lengths simultaneously. There is no noticeable interference between transmitters and receivers at any of the stations.

Only one man is required at San Diego and Phoenix, respectively. This man acts as operator and manager. He is always able, when receiving from Los Angeles, to "break" that station when it is necessary to answer the telephone, wait on a customer, or attend to other duties. The stations in each case are located near the center of the cities they serve.

In operation of all circuits the methods of the wire companies have been followed to a great extent. Ex-wire operators are employed quite generally, and the operating officials are also ex-wire men. In the operation of the duplex circuits, the two stations are tuned in at the opening hour in the morning, after which there is no stop for tuning or calling. All business as it is filed is transmitted immediately. When it is necessary to "break," the sender is requested to re-transmit all material after the last word received, so that the receiver is able to fill in the missing words before proceeding, and to turn out a complete message ready for immediate delivery.

For transmitting purposes, the sending machines described

previously in this paper are used with few exceptions, and the speed of the circuits compares favorably with that of the fast wire circuits.

A simple form of amplifier for copying signals without the necessity for wearing head telephones has proven quite successful at Los Angeles in copying San Francisco in regular commercial work.

The Federal Telegraph Company is in active competition with the wire telegraph companies on the Pacific Coast, furnishing a fast reliable telegraph service thruout the entire year. Business is increasing daily and improvements are contemplated which will still further improve the service and the scope of the work. The circuits operated and the approximate distances covered are shown in Figure 1. A table showing the wave lengths used simultaneously without interference is shown in Table 1. This table does not show the actual degree of close tuning possible as these waves were necessarily arranged to prevent interference with other than Federal Telegraph Company stations.

TABLE 1

SIMULTANEOUS TRANSMISSION AND RECEPTION

	Transmits λ (Meters)	Receives λ (Meters)	Distance in Miles Between Transmitters and Receivers	Transmitter Power in Killowatts
San Francisco....	3,500	3,250	5	6
	10,000	10,500	7†	40
	7,500	8,000	7†	30
Los Angeles.....	3,250	3,500	5	6
	3,750	2,750	3	6
Portland.....	8,000	7,500	5	30
Honolulu.....	10,500	10,000	–*	40
San Diego.....	2,750	3,750	–*	4
Phoenix.....	2,750	3,750	–*	10

* Does not receive while sending.

† Same transmitting station using two transmitting sets, and with two antennas employed.

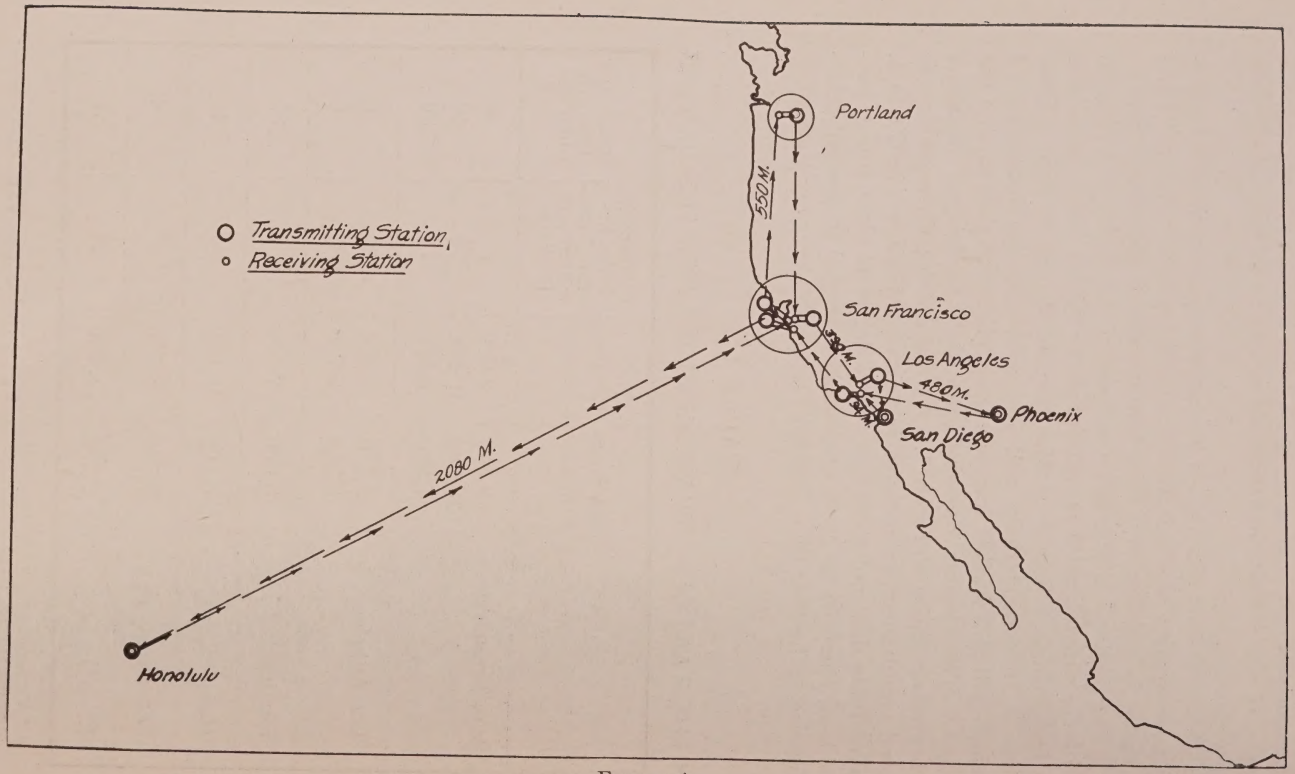
Transmitting Station
Receiving Station
Portland
550 M.
San Francisco
Los Angeles
480 M.
Phoenix
San Diego
2090 M.
Honolulu

FIGURE 1

The chief factor of success has been the ability to furnish clear, reliable signals for receiving, with a minimum expenditure of transmitted power, and with consequent low cost of operation. Good working conditions for employees, and the introduction of the latest time-saving features have also proven big factors in efficiency. Flexibility in power control and wave length regulation and the sharp tuning have assisted materially.

In the work of these stations, the matter of interference from extraneous noises has been shown to be more of a psychological than a material difficulty. An operator, trained to receive with outside disturbances present, listens only to the signals he wishes to copy, regardless of the fact that other noises around him may be considerably louder. Soundproof compartments for receiving have been demonstrated to be entirely unnecessary in this work.

The great value of the duplex system over the old style simplex station for high speed, direct work, has been the most striking feature. With the results of this work in view, the erection of simplex stations in the future, to handle any considerable amount of business, would seem to be an economic waste. In comparison: a duplex radio circuit would seem to excel a simplex non-break installation in the proportion of about 3 to 1.

SUMMARY: After considering some of the obstacles in the way of successful competition of overland radio service versus wire service, the author treats the mode of overcoming these difficulties. He recommends also radio duplex circuits; reception with loud-speaking receivers and amplifiers; trunk and way circuits from large radio centers of traffic; and relaying stations. The organization and operation of the Pacific coast chain of duplex radio stations of the Federal Telegraph Company is hen described in detail.

A SPECIAL TYPE OF QUENCHED SPARK RADIO TRANSMITTER*

By

D. Galen McCaa

(Research Engineer, John Firth, New York City)

The transmitter to be described consists partly of a special arrangement of the conductors forming the antenna; the structure presenting other circuits in conjunction with the usual open radiating circuit.

The entire transmitter is represented in Figure 1.

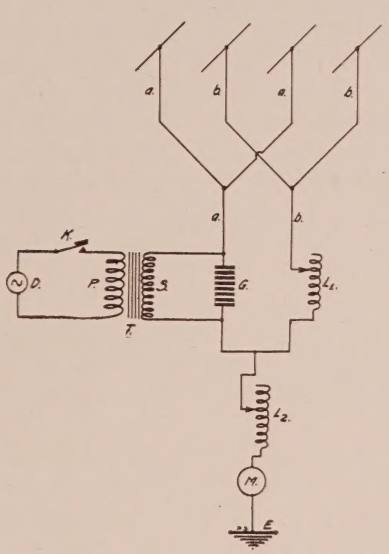

Figure 1

A number of horizontal and vertical wires, *A*, forming a "T" or an "L" type antenna, have alternating between and insulated from them a like number of wires, *B;* the wires of each

* Received by the Editor, October 15, 1918.

group being connected in parallel, and connections from each group being led to the instruments; which consist of a quenched gap, G, two inductance coils L_1 and L_2, a transformer T, a key K, and an alternator D. The earth connection is made thru the inductance L_2 and ammeter M.

Three oscillatory circuits are formed by this structure—first: the conductors A, gap G, inductance L_2, and earth E, which form an open circuit oscillator; second: the conductors A, gap G, inductance L_1, and the conductors B, which form a partially closed circuit oscillator; third: the conductors B, inductances L_1 and L_2, and the earth E, which form an open circuit oscillator.

The gap is common to the circuits A, G, L_2, E and A, G, L_1, B. These circuits are, therefore, the primary oscillatory systems and supply energy to the structure B, L_1, L_2, E which is the radiating system.

The capacity available is determined by the capacity of the conductors A to earth, which is markedly increased by the proximity of the earthed conductors B, and by the capacity found between the group of conductors A and the group B. These two capacities are charged in parallel. It may be noted here that the conductors B serve the following purposes: first, augment the capacity of the conductors A; second, form a primary oscillator in conjunction with the conductors A, and third, become the capacity of an open circuit oscillator.

The primary circuit A, G, L_2, E, is coupled to the radiating circuit B, L_1, L_2, E by the inductance L_2. This coupling is varied by the inductance L_1. The primary circuit A, G, L_1, B is coupled to the radiating circuit B, L_1, L_2, E by the inductance L_1. This coupling is varied by the inductance L_2. The circuits are closely coupled, for in addition to the electromagnetic couplings, a capacitive coupling exists between the conductors A and B.

Owing to the antenna structure employed and the close couplings presented it is imperative that the primary discharges be highly damped. With a single stationary zinc spark gap, there will be found two sets of coupling oscillations in the circuit B, L_1, L_2, E, and the structure A remains a part of the radiating system during the primary discharge, and it will be carrying current opposite in direction to the structure B. The effect will be similar to that found in a loop antenna.

The close and fixed couplings do not lend themselves readily to the use of true quenched gap effects, where the quenching is partly determined by the reaction of the secondary current.

In order that there shall be no effectual radiation from the two primary circuits, the energy of the primary oscillations must be quickly transferred to the secondary system and the gap must become an open circuit after the first few oscillations. This result is obtained by employing a very high group frequency of highly damped primary discharges.

With the usual closed circuit primary oscillator consisting of a quenched gap, condenser, and inductance, it is possible to obtain group frequencies of forty-thousand discharges per second, the number depending upon the design of the oscillator and its relation to the supply system. The damping of the oscillations in such a system is determined by the supply current, the design of the gap, and the constants of the primary oscillator. The higher the group frequency the greater will be the decrement of each primary discharge; and with the group frequencies actually employed a type of impulse excitation results.

Discharges of this type will occur in a primary oscillatory circuit when it is not coupled to a secondary circuit. The reaction of a secondary system is, therefore, not required as in true quenched gap operation.

Figure 2 is a photographic record of the discharges in an oscillator designed to produce high group frequencies, and shows the discharges that occur during the time period of one alternation; the discharge frequency is approximately thirty-five-thousand per second along the crest of the alternating current wave.

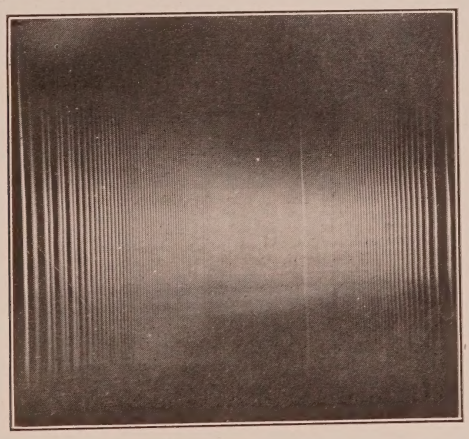

FIGURE 2

Measuring the logarithmic decrement of the oscillations in the primary system will not indicate the number of cycles in each discharge as the gap decrement is linear (and can be determined by oscillograph records).

While ideal impulse excitation—a simple rise and fall of current—may not be present, a very close approximation is attained as is indicated by the fact that secondary ampere-wave length curves are almost flat.

With primary discharges as described, the gap is quickly rendered an open circuit, the primary systems A, G, L_2, E and A, G, L_1, B cease to exist as such, and the secondary system B, L_1, L_2, E is left free to oscillate at its own natural period and with a decrement determined solely by its constants.

The secondary oscillations, when high group frequencies are employed, are continuous tho not undamped. This is consequent upon the decrement of the antenna oscillations and the group frequencies. With a low decrement and high group frequency, the antenna will receive a second impulse before its oscillations have materially declined. It is probable that the electromotive forces impressed on the gap by the secondary current "trigger" it off when adding to the supply electromotive force, and the resultant discharge in the primary is then in phase with the antenna oscillations.

The adjustments of the inductances L_1 and L_2 for maximum radiation, as indicated in the ammeter M, are not critical owing to the type of impulse excitation employed; and, while a maximum can be found, it exists thruout broad adjustments of the inductances. If, with the inductances adjusted for maximum radiation, the system is analyzed by wave length measurements, leaving the inductance values fixed, the primary circuit A, G, L_2, E will present a shorter wave length and the primary circuit A, G, L_1, B will present a longer wave length than the wave radiated by B, L_1, L_2, E. The wave radiated is determined by the capacity of the conductors B to earth and the inductance values of L_1 and L_2; on inserting a spark gap in this structure and exciting it as a primary oscillator, substantially the same wave length is found.

The dissonance between the primary systems and the radiating antenna has been found to be as high as 20 per cent, the exact value varying with the group frequency employed. This is far in excess of the 2 per cent dissonance found in true quenched gap action.

Figure 3 presents the resonance curves obtained in one case.

The curve A was read from L_2 when the primary circuit A, G, L_2, E was excited alone, the conductors B being grounded independently. The curve C was read from L_1 when the primary circuit A, G, L_1, B was excited alone, the ground lead and L_2 being removed. The curve B was read from the inductance

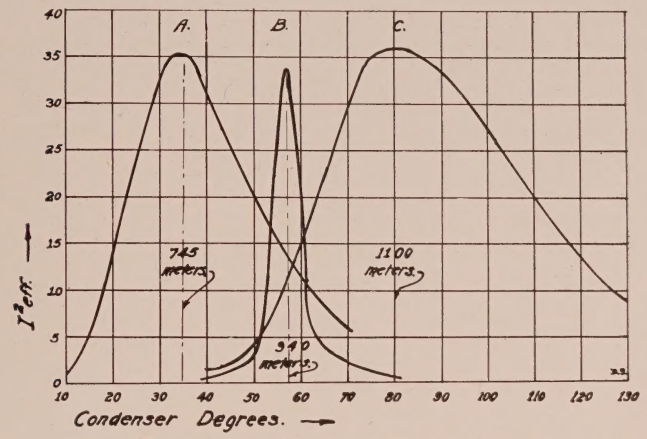

FIGURE 3

L_2 when both primary circuits were exciting the circuit B, L_1, L_2, E; and is the wave radiated. The wave lengths in this case were 745 meters for A, 940 meters for B, and 1,100 for C. It may be of interest to note that the curve B shows no evidence of the oscillations of the primary circuit A, G, L_2, E when read from L_2, and a curve read from L_1 shows the same symmetry, there being no evidence of the oscillations of the primary circuit A, G, L_1, B.

By placing a single turn coil in the conductor A immediately above the gap, both the primary wave lengths can be found. They, therefore, exist in L_1 and L_2, but are overshadowed by the more powerful oscillations of the antenna.

It will be noted that the ammeter is so placed as to be not only in the radiating antenna, but also in the primary circuit A, G, L_2, E. If the ammeter is placed immediately below the inductance L_1, the reading will be the same as if placed immediately above L_2. The values of the primary currents are usually different, and if the primary value is added to the true antenna current, different readings would be expected, dependent

on whether the ammeter is placed in one primary or in the other.

The dissonance found in this system is not consequent upon the arrangement of the circuits, but the circuits are operative *because of* the dissonance.

Between a single primary oscillator made up of a condenser, quenched gap, and inductance so designed as to produce high group frequency, and an antenna, the same dissonance effect has been found. That the structure is operative owing to the dissonance will be apparent from a consideration of Figure 4.

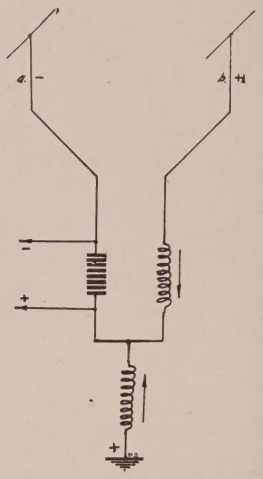

FIGURE 4

Consider the system charged as indicated by the symbols. It will be apparent that the first alternation of the discharge will flow thru the inductance as indicated by the arrows. The magnetic fields established in these auto transformers will be opposed to each other and if the currents were in phase and of equal amplitude the final result in the antennas would be zero. Cases have been observed where the three circuits were of the same period and the system was practically inoperative. With a large difference between the frequencies of the two primary systems, there is less opposition between the two auto transformers, and owing to the impulse excitation, the primaries are capable of exciting an antenna not in resonance with them, but one the period of which lies between the periods of the primaries.

Attempts have been made to reduce the phenomena in an artificial antenna or phantom circuit, but the results were not the same as found in the aerial structure.

SUMMARY: A quenched spark transmitter is so arranged that the capacity in the highly damped primary circuit is that between a special extra antenna and ground, and the primary and secondary circuits are partly inductively coupled thru a common inductance in the ground lead and partly capacitively coupled by the capacity between the special antenna and the usual secondary or radiating antenna.

Quenching effects and normal mono-wave radiation are secured. Experiments are described and an oscillogram shown whereby the group frequency and radiation characteristics are indicated.

ON THE MULTI-SECTION QUENCHED GAP*

By

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and

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It is well known that very short spark gaps (about 0.2 mm or 0.008 inches in length) possess the valuable property of causing quenching of a spark discharge. On the other hand, such gaps have a low breakdown voltage, of the order of 800 or 900 volts. This defect as regards ease of manipulation can be readily overcome by connecting a number of short gap sections in series. We thus obtain a multi-section quenched gap possessing the property of quenching because of the characteristic of the separate sections, and yet having a breakdown voltage which can be varied within wide limits by a suitable choice of the number of sections employed.

It is usually agreed that the total voltage required for a multi-section quenched gap is directly proportional to the number of sections, and that, therefore, by increasing the number of gaps, the discharge potential may be increased to any desired extent. In the following discussion, it will be shown that such an assumption is not correct, and that there exists an upper limit of voltage which cannot be exceeded by further addition of new gap sections to the series. The cause of this limitation lies in the uneven distribution of potential or potential gradient along the series of gaps.

Let us consider, for example, a quenched spark gap of the Telefunken type, consisting of fairly large, circular, metallic plates separated by thin insulating rings, and with a voltage

* Received by the Editor, September 5, 1918.

across the total gap of $V = P_z - P_o$, before the gap has broken down, as indicated in Figure 1.

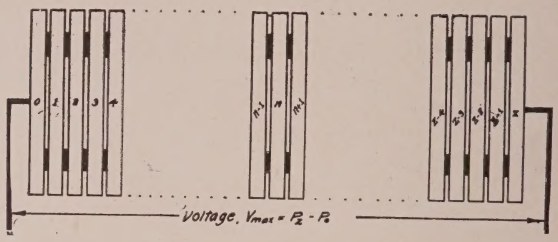

FIGURE 1

If we neglect the induction current due to imperfect insulation, we know that the total current between the plates due exclusively to variation of dielectric displacement is

$$I = \frac{d\,D}{d\,t}.$$

It is clear that the total electric flux starting say from plate $(n-1)$ does not exclusively enter the following plate, (n). Some of the lines of induction will pass directly to the oppositely charged end of the series of gaps, or will pass thru neighboring conductors to the earth, and so on. There is thus a certain leakage of the dielectric displacement current and if we denote the current entering the plate n, and, therefore, starting from it, by I_n, and the leakage current from this plate by i_n we will have for current entering the plate $n+1$, the value

$$I_{n+1} = I_n - i_n \tag{1}$$

This current can be expressed in terms of the voltage between the plates as follows:

$$I_{n+1} = (P_{n+1} - P_n)\,\omega\,C \tag{2}$$

$$I_n = (P_n - P_{n-1})\,\omega\,C \tag{3}$$

where ω signifies the angular velocity or $2\pi f$, C the capacity of the condenser formed by the two adjacent plates, and P_{n+1}, P_n, P_{n-1} . . . . , the potential of the corresponding plates.

We can write a similar expression for the current I_n:

$$i_n = (P_n - P_o)\,\omega\,c$$

or putting $P_o = 0$,

$$i_n = \omega\,c\,P_n, \tag{4}$$

where by c we understand the capacity of the plate with respect to the earth, to leads, and all other neighboring conductors except the next plates.

From (1), considering (2), (3), and (4), we have

$$\frac{c}{C} P_n = P_{n+1} - 2 P_n + P_{n-1} \tag{5}$$

The solution of this equation can be put in the form of

$$P_n = A \varepsilon^{\alpha n} \tag{6}$$

For P_{n+1} and P_{n-1} we then obtain

$$P_{n+1} = A \varepsilon^{\alpha (n+1)} = \varepsilon^{\alpha} A \varepsilon^{\alpha n} \tag{6'}$$

$$P_{n-1} = A \varepsilon^{\alpha (n-1)} = \varepsilon^{-\alpha} A \varepsilon^{\alpha n} \tag{6''}$$

By substitution we get from (5):

$$\frac{c}{C} = \varepsilon^{\alpha} - 2 + \varepsilon^{-\alpha} = (\varepsilon^{\frac{\alpha}{2}} - \varepsilon^{-\frac{\alpha}{2}})^2 = \left(2 \sinh \frac{\alpha}{2}\right)^2 \tag{7'}$$

Putting $\frac{c}{C} = k$, we obtain

$$\sinh \frac{\alpha}{2} = \tfrac{1}{2} \sqrt{k} \tag{7}$$

As the solution of (5) can also be put into the form $P_n = B \varepsilon^{-\alpha n}$, we may write the more general expression for the potential of the n-th plate, P_n, namely:

$$P_n = A \varepsilon^{\alpha n} + B \varepsilon^{-\alpha n}. \tag{8}$$

The constants A and B depend upon the values of P_o and P_z, these latter being the values of the potentials at the ends of the series of gaps.

In radio practice, two different cases may arise (of which the first is):

$$P_o = 0; \quad P_z = V_{max},$$

V_{max} being the voltage produced by the transformer when the spark circuit is directly coupled to the antenna; and (for the second case):

$$P_o = -\frac{V_{max}}{2}; \quad P_z = +\frac{V_{max}}{2},$$

when the coupling to the antenna is inductive, since in this case the neutral point of the transformer is usually connected to ground.

In the first case we have for the first of the series of gaps, where

$$n = 0,$$
$$A + B = 0;$$

and therefore

$$A = -B,$$

while at the end of the series of gaps, where $n = z$,

$$A\,\varepsilon^{a\,z} + B\,\varepsilon^{-a\,z} = A\,(\varepsilon^{a\,z} - \varepsilon^{-a\,z}) = V_{max}$$

and therefore

$$A = \frac{V_{max}}{\varepsilon^{a\,z} - \varepsilon^{-a\,z}} = \frac{V_{max}}{2\,sinh\,a\,z}.$$

Substituting these values of the expression for the potential of the n-th plate, we get

$$P_n = V_{max}\,\frac{sinh\,a\,n}{sinh\,a\,z} \tag{9}$$

which expresses the law governing the distribution of potential along the series of plates of the gap.

This potential distribution is shown graphically in Figure 2.

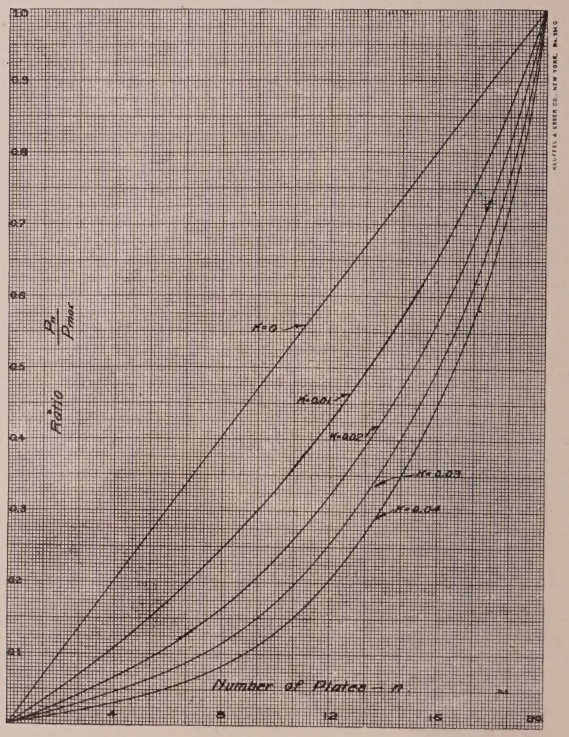

FIGURE 2

From this, we note that the voltage applied to each gap of the series is by no means the same, but increases as n, the number of gaps, increases. If we denote the voltage between the plate n and plate $n-1$ by v_n, we have

$$V_n = P_n - P_{n-1} = \frac{V_{max}}{sinh\, a\, z} \left(sinh\, a\, n - sinh\, a\,(n-1)\right)$$

and since

$$sinh\, a\, n - sinh\, a\,(n-1) = 2\, sinh\, \frac{a}{2}\, cosh\, \frac{a\,(2\,n-1)}{2},$$

we obtain directly

$$v_n = V_{max} \frac{2\, sinh \frac{a}{2}}{sinh\, a\, z}\, cosh\, \frac{a\,(2\,n-1)}{2}. \tag{10}$$

This expression can be put into another form which permits us to draw certain interesting conclusions. The form referred to is

$$v_n = V_{max} \frac{2\left(\varepsilon^{\frac{a}{2}} - \varepsilon^{-\frac{a}{2}}\right)\left(\varepsilon^{a\,n-\frac{a}{2}} + \varepsilon^{-a\,n+\frac{a}{2}}\right)}{\varepsilon^{a\,z} - \varepsilon^{-a\,z}}$$

$$= V_{max}\left(1-\varepsilon^{-a}\right) \frac{\varepsilon^{a\,n-\frac{a}{2}} + \varepsilon^{-a\,n+\frac{a}{2}}}{\varepsilon^{a\,z-\frac{a}{2}} - \varepsilon^{-a\,z-\frac{a}{2}}}$$

As the number of plates n increases, this expression approaches the limit

$$v_n = V_{max}\left(1-\varepsilon^{-a}\right) \tag{11'}$$

or

$$V_{max} = \frac{v_n}{1-\varepsilon^{-a}} \tag{11}$$

The breakdown voltage of a given gas being fixed, we see from this that the total voltage V_{max} applied to a series of gaps cannot be made to exceed the value determined by equation (11) above.

The increase in breakdown voltage of a multi-section quenched gap with the increase in the number of sections is shown in Figure 3 for the values of $k = \frac{c}{C} = 0$; 0.000625; 0.00125, 0.0025; 0.005; and 0.01. It is evident that the upper limit of spark voltage is reached for $k = 0.01$ when $n = 24$, for $k = 0.005$ when $n = 34$, and so on. Furthermore, this limit for $k = 0.01$ is about 10 times the breakdown voltage of the short gap section; while for $k = 0.005$ it is 14.6 times the same voltage, and so on.

The effect of the flux leakage on the highest obtainable gap voltage of a multi-section discharger is more fully shown by the curve of Figure 4, the abscissas being the ratio $k=\frac{c}{C}$, and the ordinates showing the greatest attainable multiple of the breakdown voltage of a short gap for a multi-section gap consisting of such short gaps connected in series.

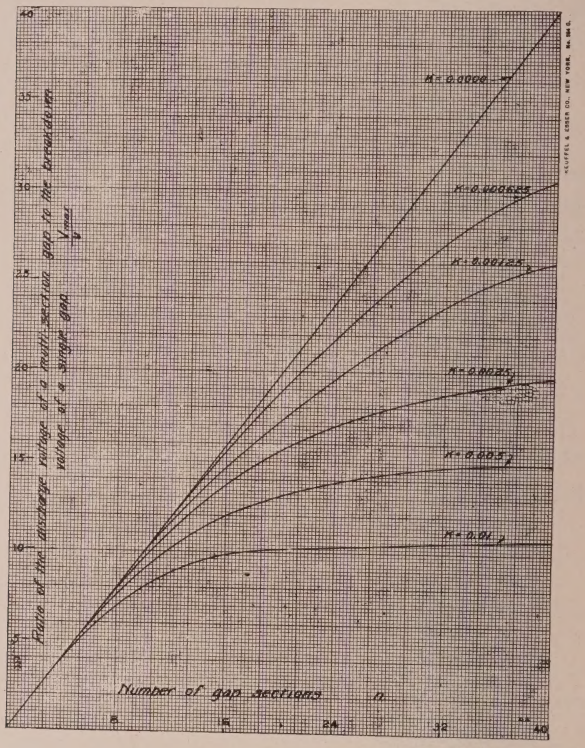

FIGURE 3

On considering the second of the above-mentioned possibilities; namely, that of inductive coupling of the spark circuit to the antenna circuit, we have

at $$n=0$$

$$-\frac{V_{max}}{2}=A+B$$

and at

$$n = z$$

$$+\frac{V_{max}}{2} = A\,\varepsilon^{\alpha z} + B\,\varepsilon^{-\alpha z}$$

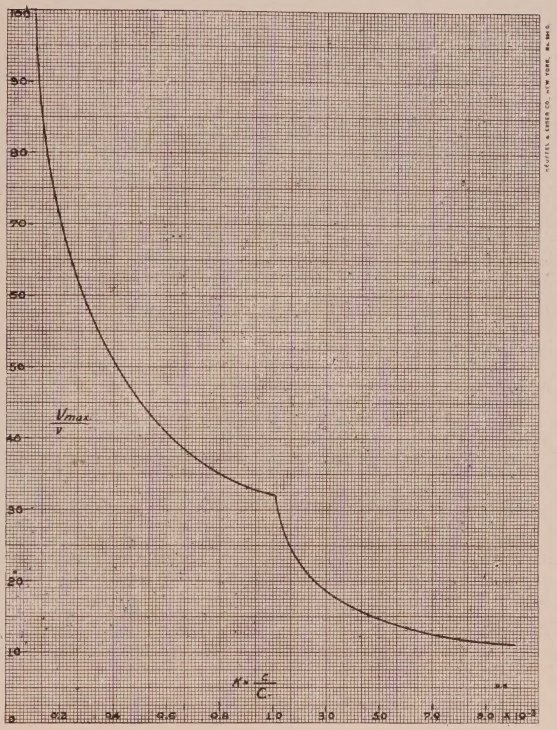

FIGURE 4

Therefore

$$A = \frac{V_{max}}{2} \cdot \frac{1+\varepsilon^{-\alpha z}}{2\,sinh\,\alpha z}$$

$$B = -\frac{V_{max}}{2} \cdot \frac{1+\varepsilon^{-\alpha z}}{2\,sinh\,\alpha z}$$

and the expression for the potential of the $n-$th plate takes the form

$$P_n = \frac{V_{max}}{2} \cdot \frac{sinh\,\frac{\alpha}{2}(2n-z)}{sinh\,\frac{\alpha z}{2}} \qquad (12)$$

This distribution of potential is shown by the curves of Figure 5, these curves being drawn for the same values of k, as in Figure 2; namely, $k=0.04$; 0.03; 0.02; 0.01; and 0. By comparison with Figure 2, we see that the distribution or gradient potential is much more uniform, and that the middle gap sections in this case have less stress on them, the excess voltages being equal at each end of the series of gaps.

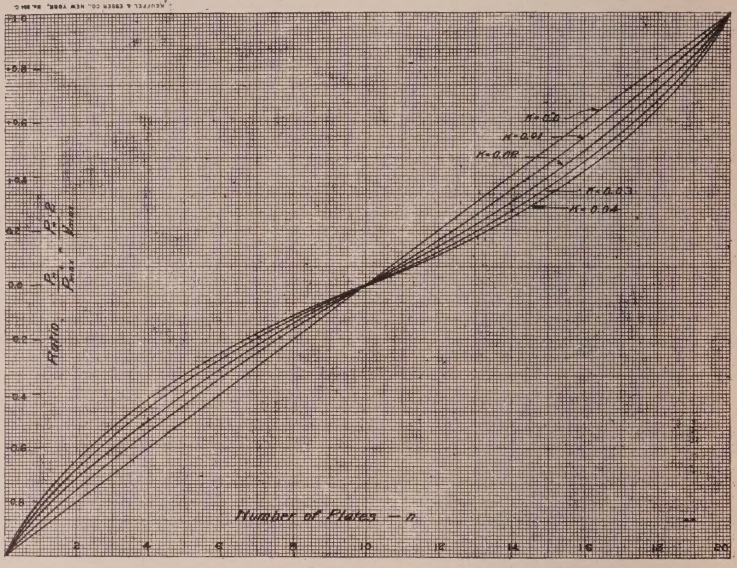

FIGURE 5

For the voltage applied to the gap section between plate n and plate $n-1$, we obtain

$$v_n = P_n - P_{n-1} = V_{max} \frac{\sinh \frac{a}{2}}{\sinh \frac{az}{2}} \cdot \cosh \left[\frac{a}{2} (2n - z - 1) \right] \quad (13)$$

The voltage of the last gap of the inner series will be

$$v_z = V_{max} \frac{\sinh \frac{a}{2}}{\sinh \frac{az}{2}} \cdot \cosh \frac{a}{2} (z-1).$$

Putting this under the form

$$v_z = V_{max} \frac{(1-\varepsilon^{-\alpha})}{2} \cdot \frac{\varepsilon^{\frac{\alpha}{2}(z-1)} + \varepsilon^{-\frac{\alpha}{2}(z-1)}}{\varepsilon^{\frac{\alpha}{2}(z-1)} - \varepsilon^{-\frac{\alpha}{2}(z+1)}},$$

we see that with increasing z, this tends toward the limit

$$v_z = V_{max} \cdot \frac{1-\varepsilon^{-\alpha}}{2} \qquad (14')$$

From this we obtain

$$V_{max} = \frac{2\,v_z}{1-\varepsilon^{-\alpha}} \qquad (14)$$

Consequently, for this case of the inductive coupling of the spark and antenna circuits, just as in the preceding case for direct coupling, there exists an upper limit to the discharge voltage of the entire series of gaps. When we are given the breakdown voltage of the individual section and the "flux leakage," this limiting value is twice as high in the case of the inductive coupling as in the case of direct coupling.

SUMMARY: The authors consider the relation between the breakdown voltage of a series of quenched gap sections and that of a single section. Because of electric flux leakage from each plate to nearby plates and neighboring conductors, the relation of direct proportionality does not hold. The breakdown voltage of a number of gaps of given length can not be made to exceed a limiting value, given in the paper. The limiting value in question is shown graphically for various values of flux leakage and breakdown voltage of gap.

When spark circuit and antenna circuit are coupled magnetically, the available limiting breakdown voltage is twice that for direct coupling with one side of the high voltage transformer grounded.

A STUDY OF ELECTROSTATICALLY COUPLED CIRCUITS*

By

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With a view to justifying an extended investigation of electrostatic coupling—if such a justification be needed—let us consider one application which this kind of coupling might have in radio communication. This is the problem of producing harmonic oscillations in an antenna. The advantage of such an arrangement is apparent to an experimenter who desires to use a large antenna for receiving signals, and yet who, on account of the law or for other reasons, must use in transmitting, a wave length which is but a fraction of the natural, or fundamental, wave length of the antenna circuit. If his antenna circuit could be made to oscillate with a wave length which is the first harmonic of the fundamental, there would be emitted a wave which would have only one-third the length of the fundamental. If this were not short enough for the purposes, the second harmonic might be used.

Just before private radio communication was prohibited, I was able to produce these harmonics in the antenna which had, with the rest of its circuit, a fundamental wave length of 665 meters. I had time to try only magnetic coupling between circuits. When the primary circuit of the transmitting set was tuned to the same wave length as the fundamental of the antenna circuit, it was found that the antenna circuit oscillated fundamentally. (This statement is true, assuming that the coupling between circuits is not close enough to allow the secondary to react on the primary, thereby giving two waves, one above and one below the one otherwise expected.) When the primary circuit was tuned to a wave length one-third that of the fundamental, this first harmonic was obtained in the antenna with no trace of the fundamental or any other wave length. By reducing the wave length of the primary to one-fifth that of the fundamental, the second harmonic was obtained in the antenna.

*Received by the Editor, July 26, 1918.

For the fundamental, the primary circuit probably has only enough inductance to give the needed coupling to the antenna circuit, and all the capacity possible, consistent with the wave length, to keep the energy of the circuit at a high value, having a fixed potential available. Now if we wish to produce the first harmonic, we must reduce the product of inductance and capacity to one-ninth its value for the fundamental. But since our inductance is already no more than we need for our magnetic coupling, it must be the capacity, and consequently the energy of our system which is reduced, since $W = \frac{1}{2} CV^2$.

Electrostatic coupling between the circuits offers a solution to this problem, for we can then reduce the inductance without affecting either the coupling or the energy of the circuit.

So it was that the foregoing work seemed to lead logically to a study of the characteristics of electrostatic coupling. Mr. Laurens E. Whittemore of the Physics Department of the University of Kansas was just beginning such a study, and so we carried on the work together.

Our purpose in this research was first to investigate the mathematical theory of electrostatically coupled circuits and to test experimentally the truth of the conclusions drawn, and secondly to study by means of the Braun tube and sustained oscillations the relations existing between the variables in the electrostatically coupled circuits using various values for the coefficient of coupling.

E. Bellini[1] has worked out the mathematical theory of the general case of electrostatically coupled circuits, such as in Figure 1, by solving the differential equations which may be set up for the circuits from Kirchoff's laws. Mr. Whittemore took the easier way, and solved the equations set up in complex notation form. I will merely outline Mr. Whittemore's work.

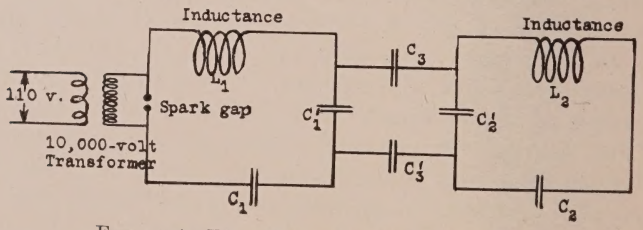


FIGURE 1—Electrostatically Coupled Circuits

[1] "La Lumière Electrique," volume 32, page 241, 1916.

The equations for potential drops and currents in the primary, secondary, and intermediate circuits are the following:

$$i_1\left(j\,p_1 L_1+\frac{1}{j\,p_1 C_1}\right)+\frac{i_1'}{j\,p_1 C_1'}=0$$

$$i_2\left(j\,p_2 L_2+\frac{1}{j\,p_2 C_2}\right)+\frac{i_2'}{j\,p_2 C_2'}=0$$

$$\frac{i_1'}{j\,p_1 C_1'}+\frac{i_3}{j\,p_3 C_3}+\frac{i_3}{j\,p_3 C_3'}+\frac{i_2'}{j\,p_2 C_2'}=0$$

$$i_1'=i_1+i_3$$

$$i_2'=i_2+i_3$$

Assuming that $p_1=p_2=p_3$, equating the determinant to zero, and solving for p^2

$$p'^2=\frac{1}{2}\left(\frac{1}{L_1G_1}+\frac{1}{L_2G_2}\right)-\sqrt{\frac{1}{4}\left(\frac{1}{L_1G_1}-\frac{1}{L_2G_2}\right)^2+\frac{k_e^2}{L_1G_1L_2G_2}}$$

$$p''^2=\frac{1}{2}\left(\frac{1}{L_1G_1}+\frac{1}{L_2G_2}\right)+\sqrt{\frac{1}{4}\left(\frac{1}{L_1G_1}-\frac{1}{L_2G_2}\right)^2+\frac{k_e^2}{L_1G_1L_2G_2}}$$

where

$$\frac{1}{G_1}=\frac{1}{C_1}+\frac{1}{C_1'}-\frac{C_t}{C_1'^2}$$

and

$$\frac{1}{G_2}=\frac{1}{C_2}+\frac{1}{C_2'}-\frac{C_t}{C_2'^2}$$

$k_e^2=\left(\frac{C_t}{C_1'C_2'}\right)^2 G_1G_2$ where k_e is the coefficient of coupling.

$$\frac{1}{C_t}=\frac{1}{C_1'}+\frac{1}{C_2'}+\frac{1}{C_3}+\frac{1}{C_3'}$$

Taking the special case where the frequencies of the two circuits are the same *before* coupling

$$\frac{1}{L_1}\left(\frac{1}{C_1}+\frac{1}{C_1'}\right)=\frac{1}{L_2}\left(\frac{1}{C_2}+\frac{1}{C_2'}\right)=4\,\pi^2\,n^2$$

where n is the natural frequency of each circuit; from which we get

$$p'=2\,\pi\,n$$

$$p''=4\,\pi^2\,n^2-\frac{C_t}{L_1C_2'^2}-\frac{C_t}{L_2C_2'^2}$$

$\frac{\lambda'}{\lambda''}=\sqrt{\frac{1-k_e}{1+k_e}}$ where λ' and λ'' are wave lengths.

When the frequencies of the two circuits are the same *after*

coupling, that is, when each circuit is tuned to the same wave length with the intermediary coupling condensers connected,

$$L_1 G_1 = L_2 G_2;$$

and we get

$$p' = \sqrt{\frac{1-k_e}{L_1 G_1}}$$

$$p'' = \sqrt{\frac{1+k_e}{L_1 G_1}}$$

$$n' = n\sqrt{1+k_e} \quad \text{or} \quad \lambda' = \lambda \frac{\lambda}{\sqrt{1+k_e}}$$

$$n'' = n\sqrt{1-k_e} \quad \text{or} \quad \lambda'' = \frac{\lambda}{\sqrt{1-k_e}}$$

In both cases, the shorter wave corresponds to the natural frequency of one of the single circuits without the coupling condenser.

To comply with the condition that each circuit have the same frequency before coupling, we excited each circuit separately (when the coupling capacities were not connected), by a spark gap and transformer, and tuned each to the desired wave length, as determined by a resonating wave meter. The circuits were then connected electrostatically and the system excited, using a spark gap in one circuit. The waves present in each circuit were determined with the wave meter.

For the other condition, we tuned each circuit when the other circuit was broken at some point other than between the coupling connections. The connections were then made and the wave lengths in each circuit determined. The theory was tested for the extreme values of coupling as well as for a number of intermediate values. We sometimes increased capacities conveniently by merely short-circuiting the condenser.

The following are the data for our observed and calculated values, from which Figure 2 is plotted:

OBSERVED					CALCULATED			
k_e	λ	λ'	λ''	$\frac{\lambda''}{\lambda'}$	λ'	λ''	k_e	$\frac{\lambda''}{\lambda'}$
.80	...	290	908	3.13	290	872	.0	1.00
.50	...	407	727	1.78			.1	1.10
.50	510	414	722	1.74	417	722	.2	1.22
.00	...	525	525	1.00			.3	1.36
.20	...	285	358	1.26			.4	1.53
.20	315	285	355	1.25			.5	1.73
.32	...	405	597	1.47	405	564	.6	2.00
.43	...	296	465	1.57			.7	2.38
.50	...	300	515	1.71	300	520	.8	3.00
.50	363	291	520	1.79			.9	4.36
.43	355	300	475	1.58	298	470	1.0	∞
.40	450	390	553	1.42	381	582		
.20	342	322	375	1.16				
.20	450	410	495	1.21				
.14	215	200	237	1.18	201	233		
.14	...	198	243	1.22	198	232		
1.00	317	225	∞	∞				
1.00	317 555	278	∞	∞				
1.00	153 555	150	∞	∞				
1.00	218	157	∞	∞				

The curve (Figure 2) gives a good comparison of observed and calculated values. We see that as our co-efficient of coupling, k_e approaches more and more closely to unity, one wave length approaches infinity under both conditions of tuning. When the circuits are in tune after coupling, while the one wave length approaches infinity, the other approaches zero. But

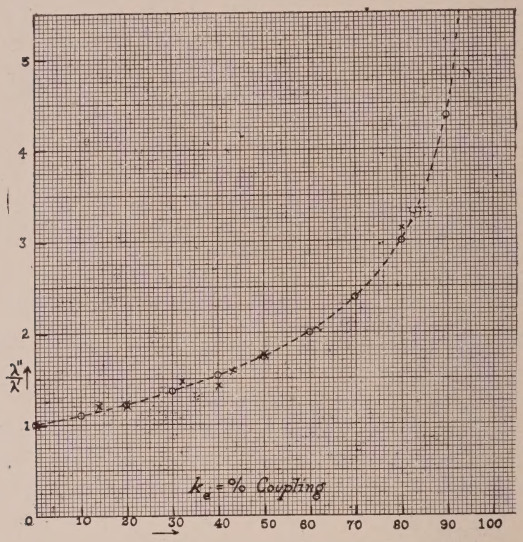


FIGURE 2

in the case of tuning before coupling, we have one wave always the same, while the other approaches infinite length with no energy content. This is surely an ideal state of things, since we can then transfer nearly all the energy of the primary to the secondary and yet have that energy in only one wave.

The Braun tube method of studying the arc phenomena of single circuits is not by any means new, but we are reasonably sure that the effects produced by electrostatically coupling a secondary circuit have never been investigated by this method.

Professor Simon[2] explored the "dynamic characteristic" of an alternating current arc by means of a Braun tube arranged so that the cathode ray pointer was deflected horizontally by the arc current and vertically by the potential difference across

[2] H. Th. Simon, "Phys. Zeitschr.," volume 6, page 297, 1905; volume 7, page 423, 1906.

the arc. The closed curve he obtains is of the form of Figure 3 and shows a phenomenon called "arc hysteresis." This shows very clearly how the variables are related and that the arc actually has a falling characteristic. In 1900, Mr. Duddell[3] showed that a direct current arc gave out a musical note when it was shunted by a condenser and an inductance, both of proper proportions. The most extensive and valuable study of the dynamic characteristics of the oscillating arc was made by Simon and his students.

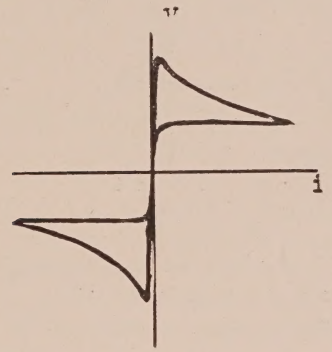


FIGURE 3

Mr. Hidetsugu Yagi[4] has investigated the reacting effect of a magnetically coupled secondary circuit on the oscillation of a carbon arc. In our experiments, we are substituting known values of electrostatic coupling for his magnetic coupling.

There are three types of oscillations which may be obtained with an arc. If there were no oscillations the current thru the arc, i_o, would be nearly constant. The condenser discharge thru the arc tends to superpose a sinusoidal current and make the current pulsating. So long as i_o is larger than the amplitude of pulsation, there is no extinction of the arc, and the oscillation is said to be of the "first type." The oscillation of this type is generally obtained in musical arcs. When the fluctuation becomes larger than i_o, there will be a period of zero current, and the arc will be extinguished for a moment. If the arc extinguishes, a constant current, i_o, will flow into the condenser and charge it up until its potential becomes sufficiently

[3] W. Duddell, "Journal I. E. E.," volume 30, page 232, 1900.
[4] Hidetsugu Yagi, "Proc. Inst. Radio Engrs.," volume 4, page 371, 1916.

high to cause the next discharge across the arc gap. This is called the "oscillation of the second type," and is most readily obtained in practice at radio frequencies, especially when there is any dissimilarity of electrode material. If the terminal potential difference, which becomes reversed at the extinction, is large enough to cause a discharge across the gap, it will light a small arc in the opposite direction. The oscillation with this reverse discharge is of the third type. The three types are diagrammatically represented in Figure 4, as taken from Mr. Yagi's paper.

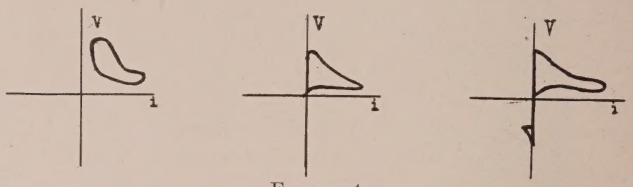


FIGURE 4

As the second type of oscillations are used in radio communication, we have used this type in our study.

In our experimental work, we studied the relations between (1) $\frac{di}{dt}$, and i in the primary, where i is current; (2) potential difference across condenser in secondary, and primary current; (3) i in secondary, and i in primary; (4) potential difference across arc, and secondary i; (5) $\frac{di_2}{dt}$, and i_2; (6) potential difference across arc, and i in the primary, which, however, was not very successful because our Braun tube was not constructed so as to give us the necessary amplitude for our potential deflections. Before beginning the above studies in electrostatic coupling, we reproduced some of Mr. Yagi's work with magnetic coupling in order to be sure that the apparatus was being used in the proper way and to accustom ourselves to the necessary manipulations.

Figure 5 shows diagrammatically the arrangement of apparatus for our work, as used with the various connections. We shall call the circuit shunting the arc the primary circuit. Our first experimental problem was to construct an arc which would give us fairly persistent oscillations in our shunt circuit. They had to be steady enough to produce a figure on the Braun tube screen which could be photographed. After many trials of

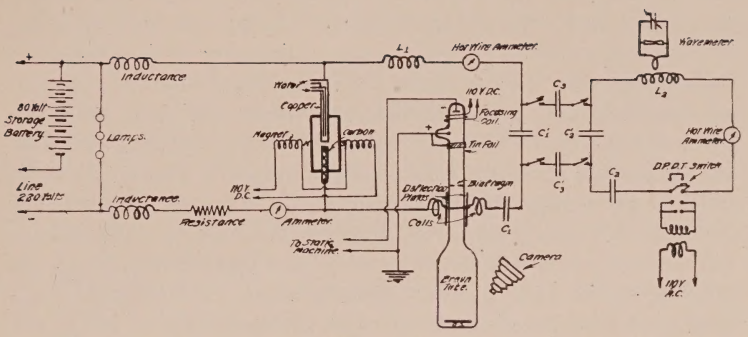


FIGURE 5

different arrangements, and failures, we finally used the enclosed arc shown in the diagram with fair success. The negative electrode was a solid carbon rod about one centimeter (0.4 inch) in diameter with its end filed off flat. This last is necessary to keep the arc from varying in length as it moves around. The carbon should be rotated slowly to prevent the arc from burning away one point on the carbon; but we did not do this, as we found it sufficient to turn the carbon part way around once in a while, or to substitute a new carbon. Sometimes we used a longitudinal magnetic field, which caused the arc to rotate about the axis of the carbon. The transverse magnetic field produced more vigorous oscillations but generally not such steady ones as no field at all.

The arc was enclosed in a porous cup which was properly closed with asbestos, and provided with a peep hole for the adjustment of the arc, and with an alcohol drip. A flame from a bunsen burner kept the porous cup hot so that the alcohol which dripped down on the inside was quickly vaporized. The alcohol vapor seemed necessary, for, as soon as the alcohol gave out the oscillations stopped. This alcohol vapor has the effect of steepening the characteristic curve of the arc.

Our Braun tube did not have some features which we wanted but we used it as it was. There was only one diafram in the tube, tho there should have been two to make the spot on the screen small and clearly defined. A focusing coil placed as indicated in the drawing helped us greatly in obtaining a bright and fairly well defined spot. The strength of the field of this coil and its direction had to be adjusted by experiment for the

best effect. We were troubled by the jumping of the beam, due probably to the accumulation of charges on various parts of the tube, until we partially covered the large end of the tube with tinfoil and put a strip of foil around the tube close to the positive electrode, grounding each of these foils along with the positive electrode. Current deflections were obtained by passing the current thru two coils placed on opposite sides of the tube so that their magnetic fields would add. In our experiments two coils of twenty turns each were used in series. For potential deflections, a couple of metal plates were held as close as possible to the tube and on opposite sides. If our plates had been sealed into the tube we would have been able to get larger deflections for the potentials used—a thing which we often needed. For operating the tube we used a two-plate Wimshurst electrostatic machine driven by a motor.

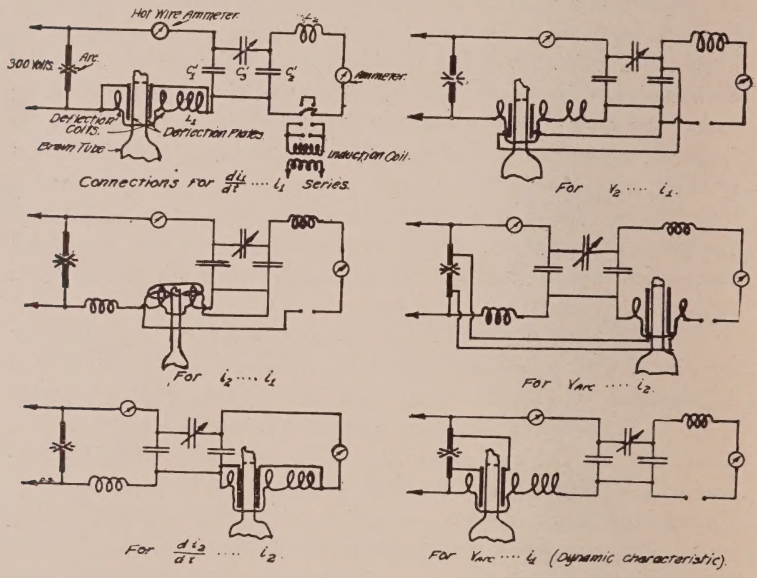


FIGURE 6

Placed a little to one side of the tube, and focused on the front of the screen, we had our camera. With an f.-6.3 anastigmat lens and Cramer's "Isochromatic" plates, an exposure of from one-fifth to three-fifths of a second was sufficient for good

photographs. Once in a while we thought our plates showed the effects of x-rays, probably from the aluminum diafram in the tube.

The ammeters used in the two oscillatory circuits were of the hot wire type, each being calibrated with the line ammeter and direct current. However, as the secondary current meter was burned out just preceding its calibration, it was calibrated, using a wire and shunt as nearly like the original as possible. At any rate, even if the values thereby given are only approximate, we know relative values from the readings.

The inductance in each circuit aside from that in the deflection coils was in the shape of a spiral. The capacity was made up of sections of Murdock molded condensers of approximately 0.0017 microfarads capacity each. The capacities of all sections were assumed equal when the coefficient of coupling was calculated. A variable air condenser, with a capacity at fifty-five scale divisions equal to that of one section of condenser, was used with the coupling capacity to make the coupling continuously variable.

When the switches shown in the secondary circuit are thrown towards the spark gap, we have a means of exciting our secondary for tuning purposes. The wave meter consisted of an inductance in series with a variable air condenser calibrated for wave lengths. A low pressure hydrogen tube was connected across the terminals of the inductance or condenser, to indicate maximum potentials in the circuit.

On the line side of the arc, there was some dead resistance for controlling the current thru the arc, as well as a large inductance in each line to prevent oscillations from the shunt circuit from getting into the line. The inductance in each line was the secondary of a commercial house-supply transformer. As an additional precaution against the oscillations getting back into the line, three incandescent lamps were placed in series across the line.

In our work we found it very convenient to short-circuit C_1, C_3, and C_2, and to use one section of condenser for C_1', and C'_2 each, leaving C_3' for varying the coupling. With this arrangement and with all the capacity we had available, the coupling could be varied from zero to over ninety per cent.

In each case, we were careful to have our circuits tuned so that they satisfied the condition of resonance before coupling. The wave length of an oscillation in the primary circuit, which seemed to be readily reproduced, was determined and the second-

ary was tuned to that, without the coupling, by means of the spark gap and transformer. Now, according to the theory which we have verified in the first part of this work, we should always have this original frequency in each of the circuits no matter what the value of the coupling. Therefore, after coupling, we placed the wave meter near the primary circuit and adjusted the arc until the tube on the meter glowed when the instrument was set for the original wave length.

The same procedure was used in obtaining each series of relations between variables. Having our deflecting coils and plates on the tube properly connected, we began with zero coupling between the circuits and increased to the maximum coupling, taking photographs as we proceeded whenever we got a new figure or a great change in a preceding one. As each photograph was taken, we noted the value of the coefficient of coupling and the primary, secondary, and line currents. For the two current deflections we used two sets of coils at right angles on the tube, which coils, so far as our work was concerned, had practically no mutual inductance (as we found by test).

The following table gives in the rows the series with the same variables while the columns give those figures of the different series with approximately the same coupling. Since a figure generally evolved gradually into the next figure taken in that series we can easily "interpolate" figures to fill out some of our columns, if we care to develop the set of figures with any certain coupling.

CLASSIFICATION OF PHOTOGRAPHS ACCORDING TO COUPLING VALUES

Numbers in table refer to numbers on photographs

Coupling % 0	30	33	42	56	61	65	70	74	78	82	87	90	92
(1) $\frac{di_1}{dt}$	..	..	..	13	..	..	..	..	14	15	16	17	18 19
(2) $\frac{V_2}{i_1}$ 20	21	22	..	23	..	21	24	..	25	26	..	27	28
(3) $\frac{i_2}{i_1}$ 29	..	..	30	31	..	32	..	33	..	34	35	36	37
(4) $\frac{V_{arc}}{i_2}$ 38	..	..	39	..	40	41	..	..	..	42 43	..	44	45 46
(5) $\frac{di_2}{dt}$ 47	..	..	..	..	48	49 50	..	51	..	52 53	54 55	56	57 58

In Figure 7, we have plotted the current values in the secondary circuit as they varied with the coupling as obtained in series (4). Similar curves were obtained for the other series except in series (1) and (3), where the second maxima seem to be missing.

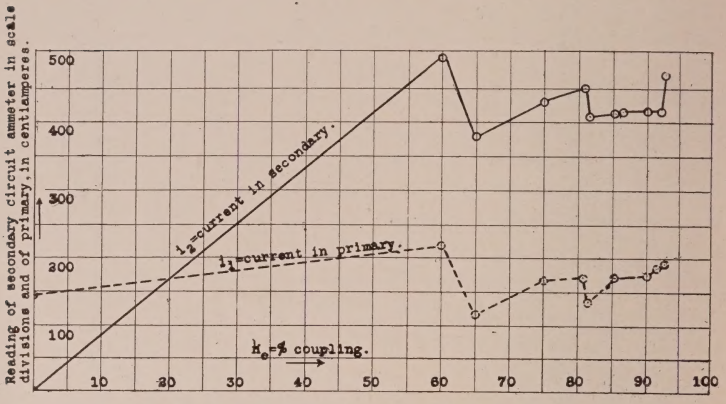


FIGURE 7

Considering Figure 7, the first maximum of current occurs at a place where the value of coefficient of coupling was sixty per cent. Now if the curve (Figure 2), showing $\frac{\lambda''}{\lambda'}$ for various coupling values, be consulted, it will be seen that for $k_e = 60\%$, $\frac{\lambda''}{\lambda'} = 2$. The second maximum on Figure 7 is at $k_e = 80\%$, at which value by curve 1, $\frac{\lambda''}{\lambda'} = 3$. By reference to the photographs of the figures obtained at these values the values of $\frac{\lambda''}{\lambda'}$ obtained above are verified. Therefore, when the ratio of the two frequencies is an integer, the root-mean-square value of the current is a maximum. The variation of the primary current, also shown in Figure 7, leads us to the conclusion as stated for the secondary circuit. Nothing definite can be said about the line current unless it is that it seems to be a minimum when the oscillating current is a maximum.

As series (1) gives us the value of $\frac{di_1}{dt}$ with respect to i_1, it is

useful for the exploration of the variation of currents, and consequently potentials, with respect to time. Let us take figures which were obtained with 82% coupling and develop the curves for time.

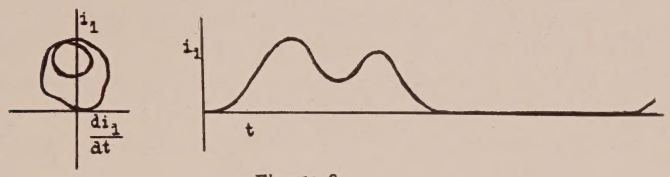


Figure 8.

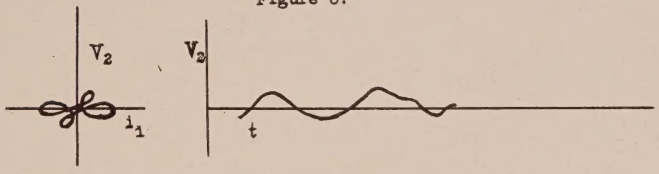


Figure 9.

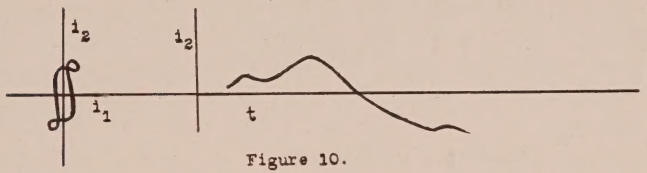


Figure 10.

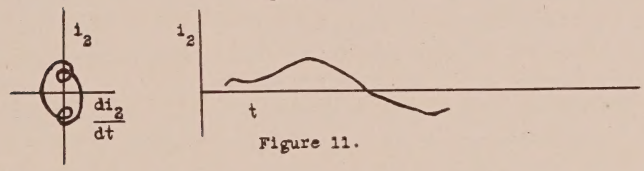


Figure 11.

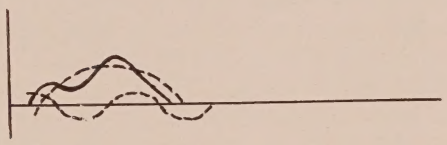


Figure 12.

FIGURES 8 TO 12

Figure 8 shows, first the figure as obtained from the photograph properly placed for development, and then the resulting curve. This is not the actual shape of our wave, as we cannot determine equal intervals of time on our figure, but it does

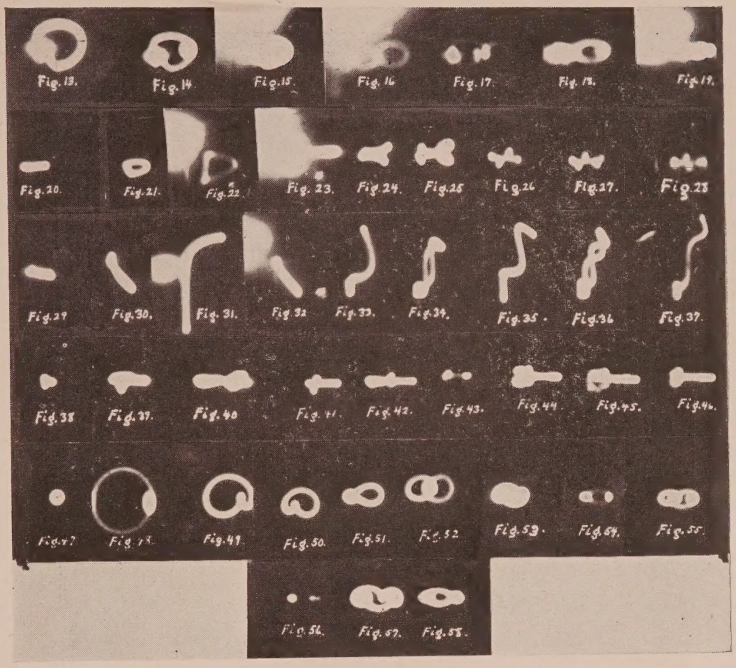
tell us something of the number and relative positions of maxima, minima, and constant values. One thing we do know is that the areas per cycle above and below the i_o line must be equal because the quantity of electricity put into the condenser (equal to $\int i\,dt$)is equal to that discharged by it.

Figure 9 gives the potential across the secondary condenser as it varies with time. This is obtained from the figure to the left by comparison with the curve obtained in Figure 8. By the same method Figure 10 is drawn. As Figure 10 plots the relation between secondary current and time, we should be able to get the curve of the same shape, by developing the cyclic diagram of the secondary current and its time rate of change as shown in Figure 11. It will be seen that these figures do agree. Figures 9, 10, and 11 are drawn for only a half cycle or a little more. The relation between the potential difference across the arc and the secondary current is not developed because of the uncertainty of the path as shown by the photograph. Figure 12 shows how the addition of two sine curves, one with three times the frequency of the other gives a curve similar to the one obtained in Figure 10. One of the shape of Figure 8 may be obtained by adding the two curves as above if the phase relations are changed a quarter of a period. This relation between the frequencies is in agreement with the determination made heretofore.

Figures subsequent to Figure 12 are photographs of the figures produced on the Braun tube screen. The figures of the same series or those with the same coupling value may be picked out by reference to the table on a preceding page.

From this study one is encouraged to believe that electrostatic coupling should have a place in the transference of energy between radio circuits first, because a high degree of coupling is possible and second, because there is practically only one wave in the circuits when such a high coupling value is used.

I desire to thank Mr. Laurens E. Whittemore, of the Physics Department, of the University of Kansas, for his constant and untiring direction and help in this work. To the Department itself, I wish to express my appreciation for the use of apparatus used in this research. This apparatus is shown in Figures 59 and 60.



FIGURES 13 THRU 58

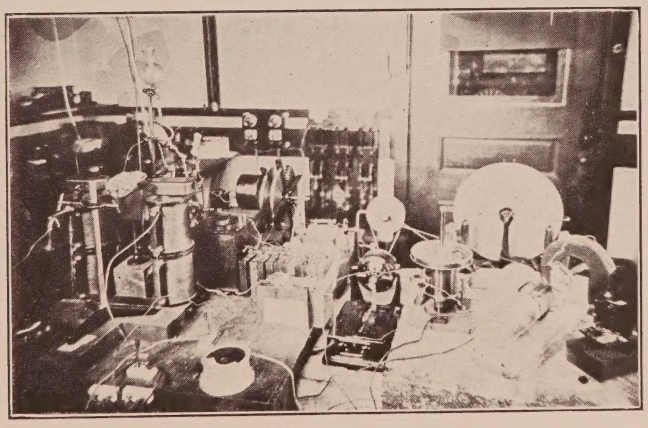


FIGURE 59

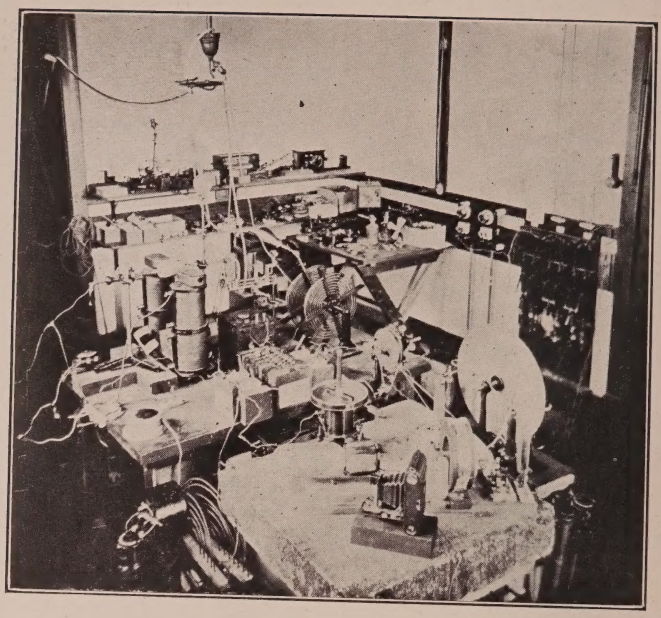


FIGURE 60

SUMMARY: The foregoing paper tells first of an investigation of the mathematical theory of electrostatically coupled circuits, and of the experimental verification of the conclusions drawn; and second, of the study, by means of the Braun tube and sustained oscillations, of the relations existing between the variables in the electrostatically coupled circuits using various values for the coefficient of coupling.

It is found by theory and also by experiment that by one method of tuning, as the circuits are coupled closer, one wave length remains constant while the other approaches infinity, thereby concentrating an increasing proportion of the energy in the one wave. It is shown by curves and by Braun tube figures that when the ratio of the two wave lengths is a whole number, the root-mean-square value of the current is a maximum.

A number of Braun tube photographs are given to show the relations between the various currents and voltages in the circuits.

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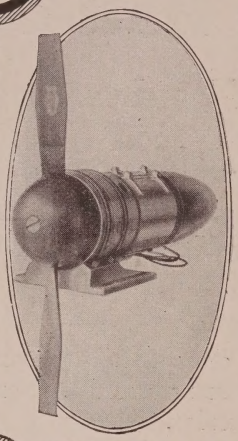

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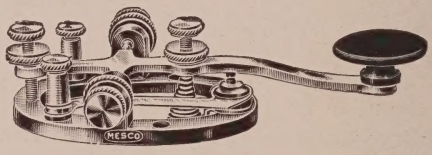

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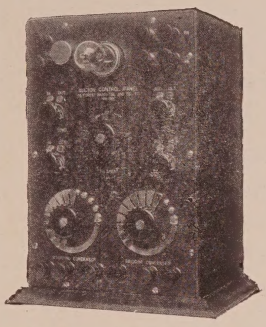

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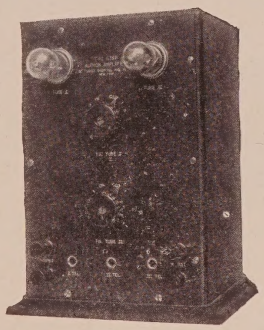

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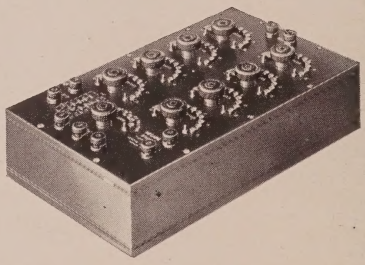

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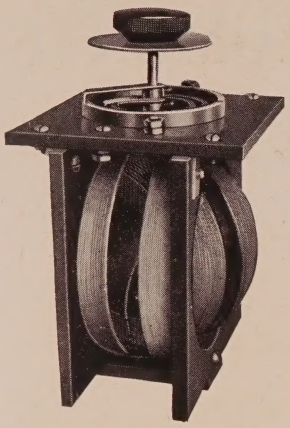

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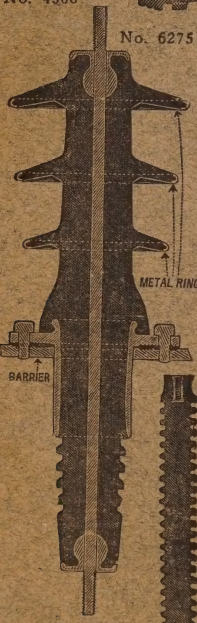

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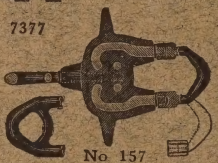

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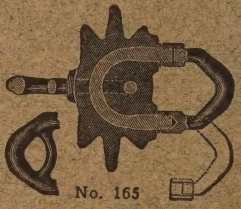
No. 6277

No. 6833



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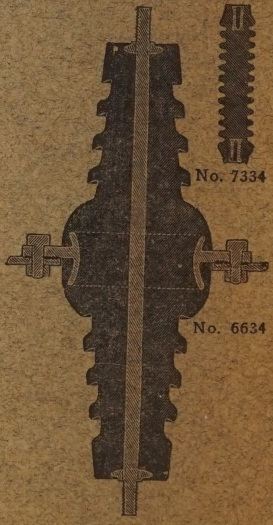

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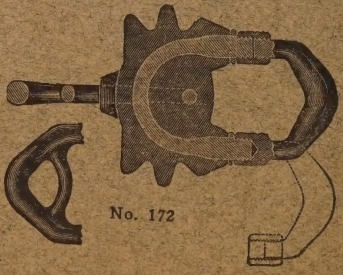

No. 172

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